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CONDENSATION HEAT TRANSFER OF STEAM ON A SINGLE  
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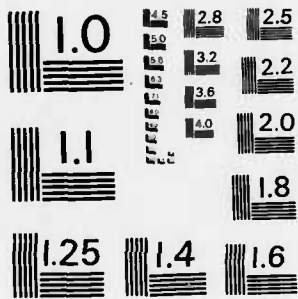
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# NAVAL POSTGRADUATE SCHOOL

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## THESIS

CONDENSATION HEAT TRANSFER OF STEAM  
ON A SINGLE HORIZONTAL TUBE

by

Kenneth A. Graber

June 1983

Thesis Advisor:

P. J. Marto

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Condensation Heat Transfer of Steam on a Single  
Horizontal Tube

by

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Lieutenant, United States Navy  
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Submitted in partial fulfillment of the  
requirements for the degree of

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from the

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## ABSTRACT

An experimental apparatus was designed, constructed and instrumented in an effort to systematically and carefully study the condensation heat-transfer coefficient on a single, horizontal tube. A smooth, thick-walled copper tube of length 133.5 mm, with an outside diameter of 15.9 mm and an inside diameter of 12.7 mm was instrumented with six wall thermocouples. The temperature rise across the test section was measured accurately using quartz crystal thermometers. The inside heat-transfer coefficient was determined using the Sieder-Tate correlation with leading coefficient of 0.029. Initial steam side data were taken at atmospheric pressure to test the data acquisition/reduction computer programs.

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# NOMENCLATURE

$A_1$	Inlet fin area ( $m^2$ )
$A_2$	Outlet fin area ( $m^2$ )
$C_i$	Sieder-Tate Coefficient
$C_p$	Specific heat (Kj/Kg - K)
$D_i$	Inside diameter of test tube (m)
$D_o$	Outside diameter of test tube (m)
$D_r$	Outside diameter at outlet end (m)
$h_i$	Inside heat-transfer coefficient ( $W/m^2 - K$ )
$h_o$	Condensation heat-transfer coefficient ( $W/m^2-K$ )
$k_{cu}$	Thermal conductivity of copper ( $W/m-K$ )
$k_f$	Thermal conductivity of water evaluated at $T_b$ ( $W/m-K$ )
$L_1$	Inlet fin length (m)
$L_2$	Outlet fin length (m)
$L$	Condensing length (m)
LMTD	Log mean temperature difference ( $^{\circ}C$ )
$\dot{m}$	Mass flow rate (kg/s)
Nu	Nusselt number
$Nu_c$	Computer generated Nusselt number
$P_1$	Fin parameter 1
$P_2$	Fin parameter 2
Pr	Prandtl number

$Q$	Heat flow rate (W)
$Q_p$	Heat flux based on outside area ( $W/m^2$ )
$Re$	Reynolds number
$R_m$	Wall resistance based on outside area ( $m^2-K/W$ )
$T_1$	Inlet temperature to test section ( $^{\circ}C$ )
$T_2$	Outlet temperature from test section ( $^{\circ}C$ )
$T_b$	Bulk fluid temperature ( $^{\circ}C$ )
$T_s$	Steam temperature ( $^{\circ}C$ )
$T_w$	Average wall temperature ( $^{\circ}C$ )
$T_{w1}-T_{w6}$	Wall temperatures ( $^{\circ}C$ )
$U_o$	Overall heat transfer coefficient based on outside area ( $W/m^2-K$ )
$V_w$	Cooling Water velocity (m/s)

#### Greek Symbols

$\mu_f$	Dynamic viscosity of water evaluated at $T_b$
$\mu_w$	Dynamic viscosity of water at average inner wall temperature ( $N-S/m^2$ )
$v_f$	Specific volume of fluid ( $m^3/Kg$ )
$\eta_1$	Inlet fin efficiency
$\eta_2$	Outlet fin efficiency

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## I. INTRODUCTION

### A. SIGNIFICANCE

Experimental studies have shown that enhancement techniques applied on the steam side of horizontal condenser tubes may significantly reduce the thermal resistance and thus reduce the overall size and weight of the condenser. Several workshops and conferences on heat exchangers have addressed specific areas in need of research {Refs. 1,2,3}. Recently, there have been many investigations into possible alternatives for enhanced heat-transfer surfaces in the design of heat exchangers {Refs. 2,4,5,6,7}. Webb {Ref. 8} in 1980 published an excellent review of enhancement methods as applied to condensers.

Enhancement techniques can generally be divided into two major categories: water-side enhancement and steam-side enhancement. Water-side enhancement is covered extensively by Bergles & Jensen {Ref. 9}. Various steam-side enhancements include low integral fins, surface coatings, fluted tubes and roped tubes.

The goal of any enhancement technique is to lower the thermal resistance to the point where the technique becomes economically feasible. Although Bergles & Jensen {Ref. 9} show that extensive reduction in thermal resistance can be obtained on the water-side, it is felt that a significant



portion of the overall thermal resistance can be reduced by enhancement techniques on the steam-side. Both methods must be examined independently because the best enhancement for one side may not be the best for both sides.

Several research efforts have been undertaken at the Naval Postgraduate School to model steam surface condensers and analyze their thermal performance numerically {Refs. 10,11,12}. Based on numerous computer runs used to analyze different combinations of both inside and outside enhancements, it is felt that further experimental research should be conducted on steam-side enhancement techniques.

#### B. OBJECTIVE

The objective of this research effort was to obtain smooth-tube baseline data necessary to act as the standard for future enhancement techniques. Both the inside and outside heat-transfer coefficients had to be identified and all experimental methods used to obtain and reduce the recorded data had to be well documented so that future testing using enhanced tubes would be performed under identical conditions.

## II. DESCRIPTION OF EXPERIMENTAL APPARATUS

### A. OVERVIEW OF SYSTEM

The experimental apparatus used in this investigation, as described in Reference 13, was constructed of stainless steel and 152.4 mm (6 in) diameter Corning Pyrex glass piping. An overall schematic of the system is shown in Figure 2.1 and a photograph is shown in Figure 2.2. A boiler section 304.8 mm (12 in) in diameter and 487.7 mm (19.2 in) in height, with a 304.8 mm (12 in) to 152.4 mm (6 in) reducing section, provides steam for the system. Ten Watlow 4000-Watt, 480-Volt stainless steel immersion heaters are used to provide input power. Each heater is 15.9 mm (5/8 in) diameter and 279.4 mm (11 in) long. All heaters are connected in parallel.

Steam travels up the glass piping to a height of 3.1 m (10 ft) and makes a 180-degree bend followed by a 1.52 m (5 ft) straightening section prior to passing through the condenser test section. Two helically-wound, water cooled coils of 9.5 mm (3/8 in) diameter copper tubing act as a dump condenser to remove all excess steam. A 25.4 mm (1 in) diameter stainless steel tube returns condensate by gravity to the boiler.

## B. CONDENSER TEST SECTION

The condenser test section is made of stainless steel, 152.4 mm (6 in) in diameter and 457.2 mm (18 in) in length. Figure 2.3 shows a schematic and Figure 2.4 shows a photograph of the test section. Steam is condensed on a single horizontal tube. Two types of smooth test tubes were constructed of high-grade copper to provide baseline data for inside and outside heat-transfer coefficients. An instrumented tube, constructed as shown in Figure 2.5, and an uninstrumented tube of the same dimensions were used to obtain initial data. The uninstrumented tube was constructed identical to the instrumented tube but there were no channels machined for thermocouple installation. The active condensing length was 133.3 mm (5.25 in) with a suitable correction applied for the "fin" effect created by both ends of the tube not being in direct contact with the steam on the outside, but cooled by water on the inside. The fin-effect calculations are described in Appendix A.

The test tube is held in place by nylon holding rings as described in Reference 13. An additional O-ring was placed inside the inlet section to prevent cooling water from leaking into the grooves of the instrumented test tube. Nylon was used to minimize axial conduction from the test section. A nylon mixing chamber described in Reference 13 was placed in the outlet side prior to measuring the temperature to ensure thorough mixing of the coolant. A 114.3 mm

(4.5 in) diameter double glass window, heated by hot air to prevent fogging, was used to provide visual observation of the condensing process.

A 12.7 mm (0.5 in) port at the dump condenser section was used as an overpressure relief line and boiler fill line. An in-line 0.108 MPa (1 psig) relief valve was used to allow gases to escape while warming up the system. A 12.7 mm (0.5 in) vacuum valve was placed in a branch line off of the relief line to allow filling of the boiler as described in Appendix B. All connections were assembled with Swagelok fittings sealed with Teflon ferrules to ensure leak tightness.

#### 1. Cooling Water System

A closed loop cooling water system was designed and constructed to circulate cooling water through the test section. A 0.001 cu-m (2.8 cuft) stainless-steel tank was used as a reservoir which fed the suction end of a close coupled centrifugal pump rated at  $0.0022 \text{ m}^3/\text{s}$  (11 GPM) at 12.19 m (40 ft) of head. A 19.1 mm (3/4 in) diameter bronze needle valve was used to regulate the flow which was monitored by a rotameter with a full-scale range of  $6.94 \text{ E-4 m}^3/\text{s}$  (11GPM). See Figure 2.6 for details. The maximum flow rate through the test tube was  $4.57 \text{ m/s}$  (15 fps) at an inlet temperature of  $15.6^\circ\text{C}$  ( $60^\circ\text{F}$ ). The centrifugal pump needle valve arrangement provided a flow rate accuracy of 0.5 percent on a scale with 100 divisions. After leaving

the condenser test section, the water was cooled back down to the 15.6°C (60°F) bath temperature by means of a 11.73 kW (40,000-BTU/Hr) direct expansion heat exchanger. The heat-exchanger refrigerant dissipates the heat to the atmosphere through a 10.55 kW (3 ton) air-conditioning unit. The chiller section is illustrated in Figure 2.7.

The closed loop cooling water system was chosen in order to more closely monitor the water flow rate and the inlet temperature to the test condenser tube. The reservoir is easily filled by use of the installed fill line and drained by use of a siphon tube.

## 2. Test Condenser Tubes

Initial smooth tube data were taken using an instrumented copper tube as illustrated in Figure 2.8. Construction of the instrumented tube was carefully performed in accordance with Figure 2.5. The instrumented tube must be installed according to the instructions as outlined in Appendix D to prevent damage to thermocouple wires and leakage from the system. Each wall thermocouple should be checked for proper operation prior to taking any data.

## C. DUMP CONDENSER SYSTEM

A dump condenser is installed to condense excess steam from the test section. Cooling water is supplied from tap water through two parallel, helically-wound, 9.5 mm (3/8 in) diameter, copper coils. One smaller diameter coil is placed

inside the other, while both are 457.2 mm (18 in) high. The tap water flow rate is controlled by a 19.05 mm (3/4 in) diameter bronze needle valve and is monitored using a rotameter. System internal pressure can be controlled by reducing the flow of cooling water to the dump condenser. For a given boiler power input, a dump condenser rotameter reading will correspond to a system pressure.

#### D. VACUUM SYSTEM

Two operational vacuum systems are available to maintain sub-atmospheric conditions within the apparatus; an air ejector, powered by 1.1 MPa (160 psig) air supplied by the Mechanical Engineering Department reciprocating air compressor, and a portable mechanical vacuum pump (Figure 2.6). Either system may be used to initially draw down the pressure but only the air ejector may be used while the system is in operation due to the lack of a nitrogen cold trap on the mechanical vacuum pump. The vacuum system inlet valve can be used to throttle the air ejector to maintain any system pressure above 13.8 kPa (2 psia). This system is also useful in removing noncondensable gases from the apparatus. The sequential drawing down of vacuum on the system while steaming, shutting the vacuum inlet valve and raising the pressure to about 13.8 kPa (2 psia) by adjusting the dump condenser throttle valve was found to be an effective method of removing noncondensable gases. This procedure should be repeated about three times.

The system will not maintain vacuum due to cracked silver soldered connections at the base of the dump condenser section. The copper tubing used as a dump condenser penetrates the stainless steel base and was sealed with silver solder which cracked, producing small leaks.

## E. INSTRUMENTATION

### 1. Heater Power Control

Power input to the apparatus is regulated by a voltage sensing circuit. Line voltage (440-VAC) is fed into a differential input precession voltage attenuator which divides the line voltage by one-hundred. This stepped-down voltage passes through a True Root Mean Square converter stage on which the integrated period has been reduced to about 1 ms. The output of the TRMS converter is buffed and compared to a reference voltage provided by a potentiometer mounted on the front panel. See Figure 2.9 for a general view of the control panel. The comparator output is fed to the control input of a Halmar silicon-controlled rectifier power supply which provides the voltage applied to the heater elements. The buffered output of the TRMS converter is amplified and filtered to provide a normalized voltage output proportional to the actual voltage output of the power supply which is monitored by the data acquisition/reduction system. A line diagram is provided in Figure 2.10.

## 2. Pressure Measurement

A U-Tube mercury manometer, calibrated in millimeters, is installed to measure system pressure. The pressure tap is located at the test section and is tilted upward to avoid steam from collecting in the manometer (Figure 2.4). A vacuum valve is installed in the pressure line to prevent condensation from accumulating in the manometer. A small amount of water eventually collects in the manometer, but this discrepancy is taken into account by the data acquisition/reduction software with manual input to the keyboard of mercury height followed by water height.

## 3. Temperature Measurement

Various temperatures are monitored throughout the system to include: 1. test section cooling water inlet and outlet, 2. steam, 3. condensate return, 4. ambient, 5. test tube wall and 6. cooling water reservoir. The temperature rise across the test section is measured by a Hewlett-Packard quartz crystal thermometer accurate to  $0.04^{\circ}\text{C}$ . The location of the temperature probes are shown in Figure 2.4. The cooling water reservoir temperature is monitored by a direct readout alcohol-in-glass thermometer. All other temperature measurement is accomplished by copper-constantan thermocouples: two for the steam, six for the test tube wall and one for the condensate return. Each temperature measurement, except for the cooling water reservoir, is read directly by a Hewlett-Packard 3497A



data acquisition system, which is controlled by a Hewlett-Packard 9826 computer.

During operation, the six wall thermocouples experienced temperature fluctuations on the order of  $\pm 10 \mu\text{V}$ . Therefore, each thermocouple was scanned for ten seconds and the ten readings were averaged to obtain a more accurate measurement. All other thermocouples maintained a steady readout with only  $1.0 \mu\text{V}$  fluctuation. The quartz crystal thermometer appeared to operate very well with no fluctuations.

Two of the thermocouples were calibrated. One thermocouple was made from the beginning of a spool of copper-constantan wire and one was made from the end. All other thermocouples were fabricated from wire on this spool. It was assumed that the properties of the copper and constantan do not change along a given section of wire for any given spool. Both thermocouples were calibrated by the method described in Appendix E.

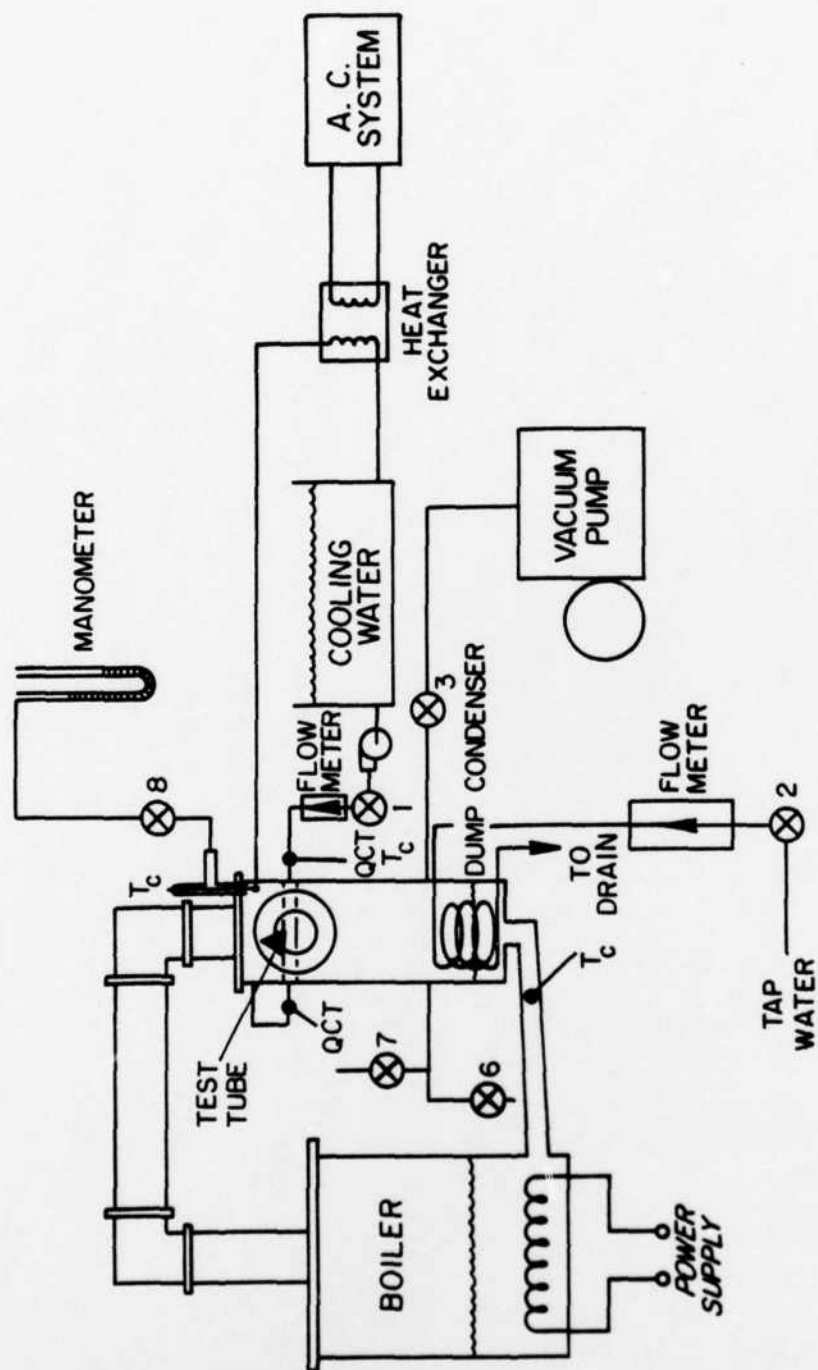


Figure 2.1 Schematic of Test Apparatus

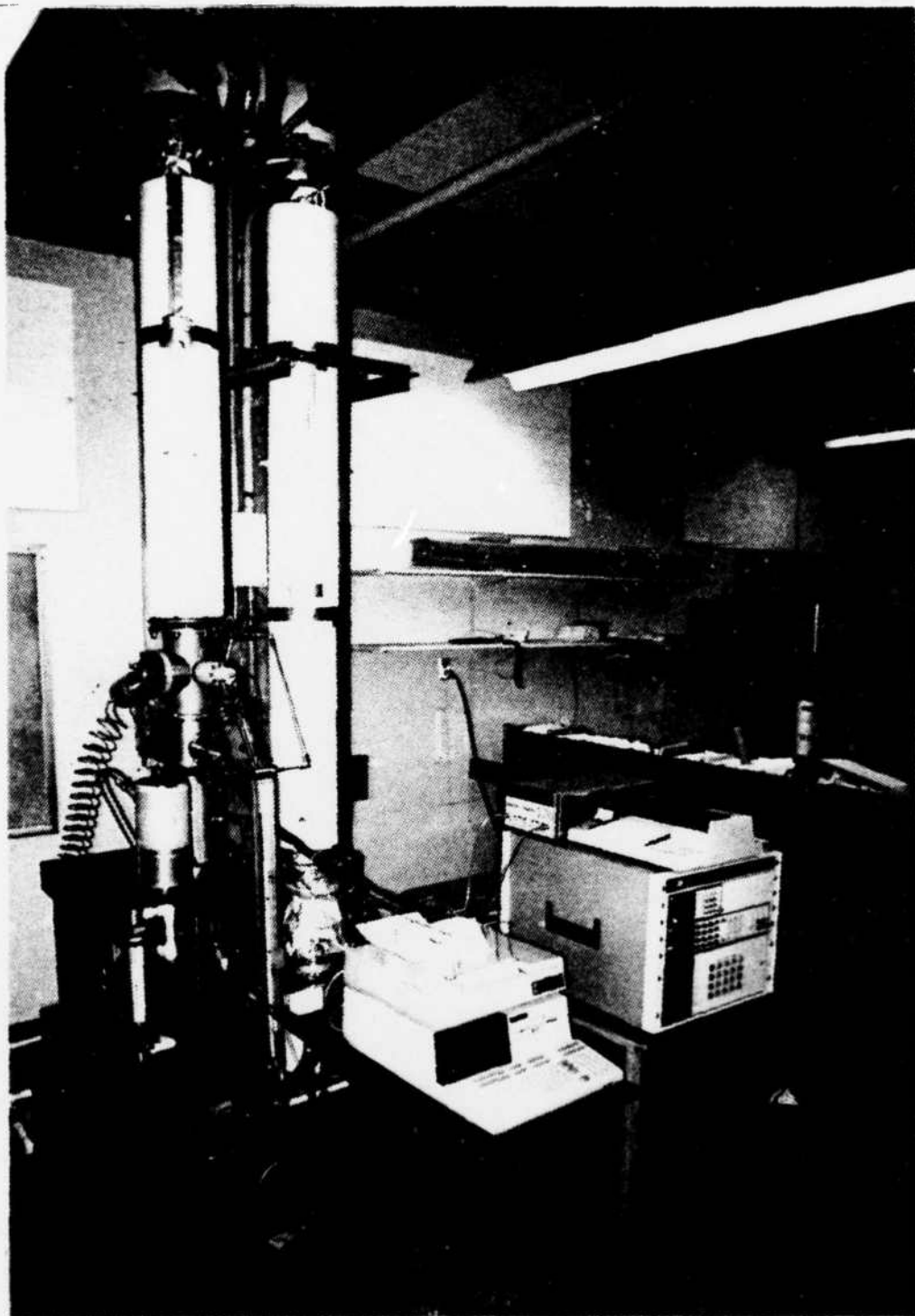


Figure 2.2 Photograph of Overall System Showing  
Data Acquisition System

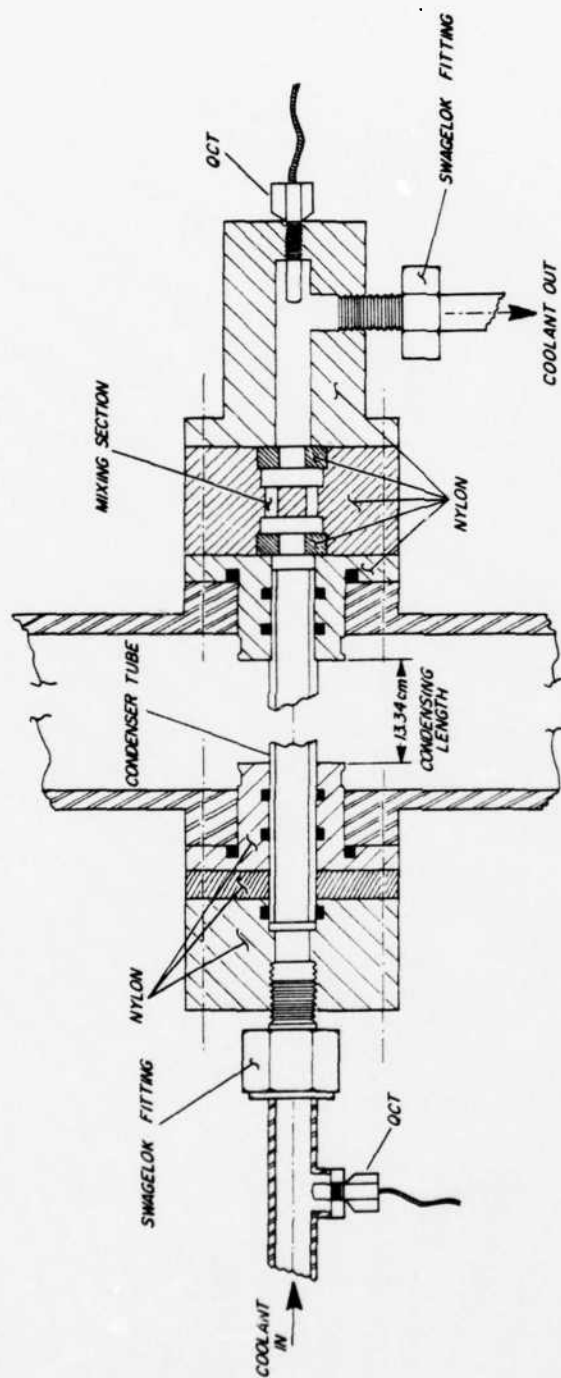


Figure 2.3 Schematic of Test Section

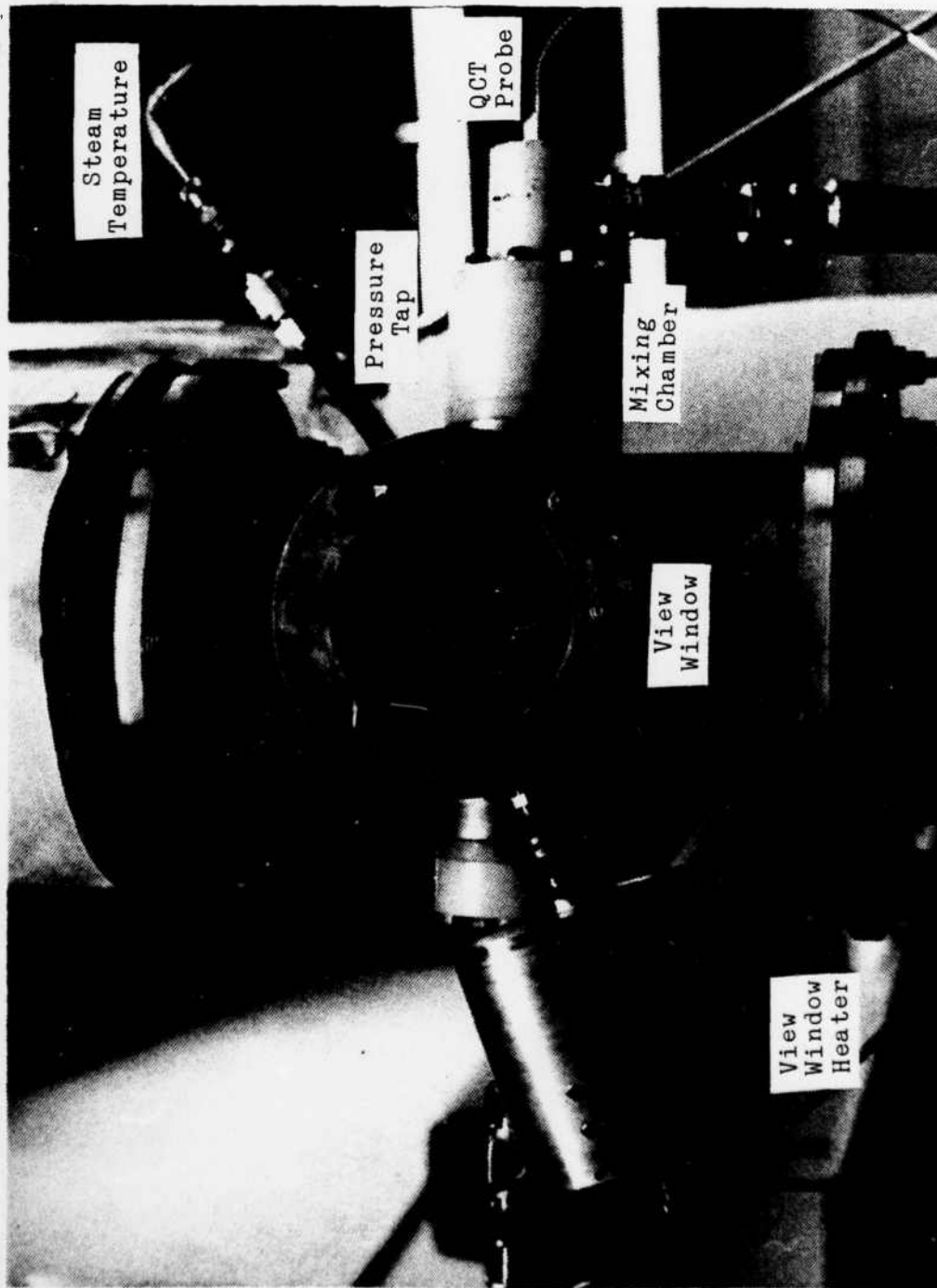
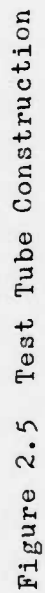


Figure 2.4 Photograph of Test Section



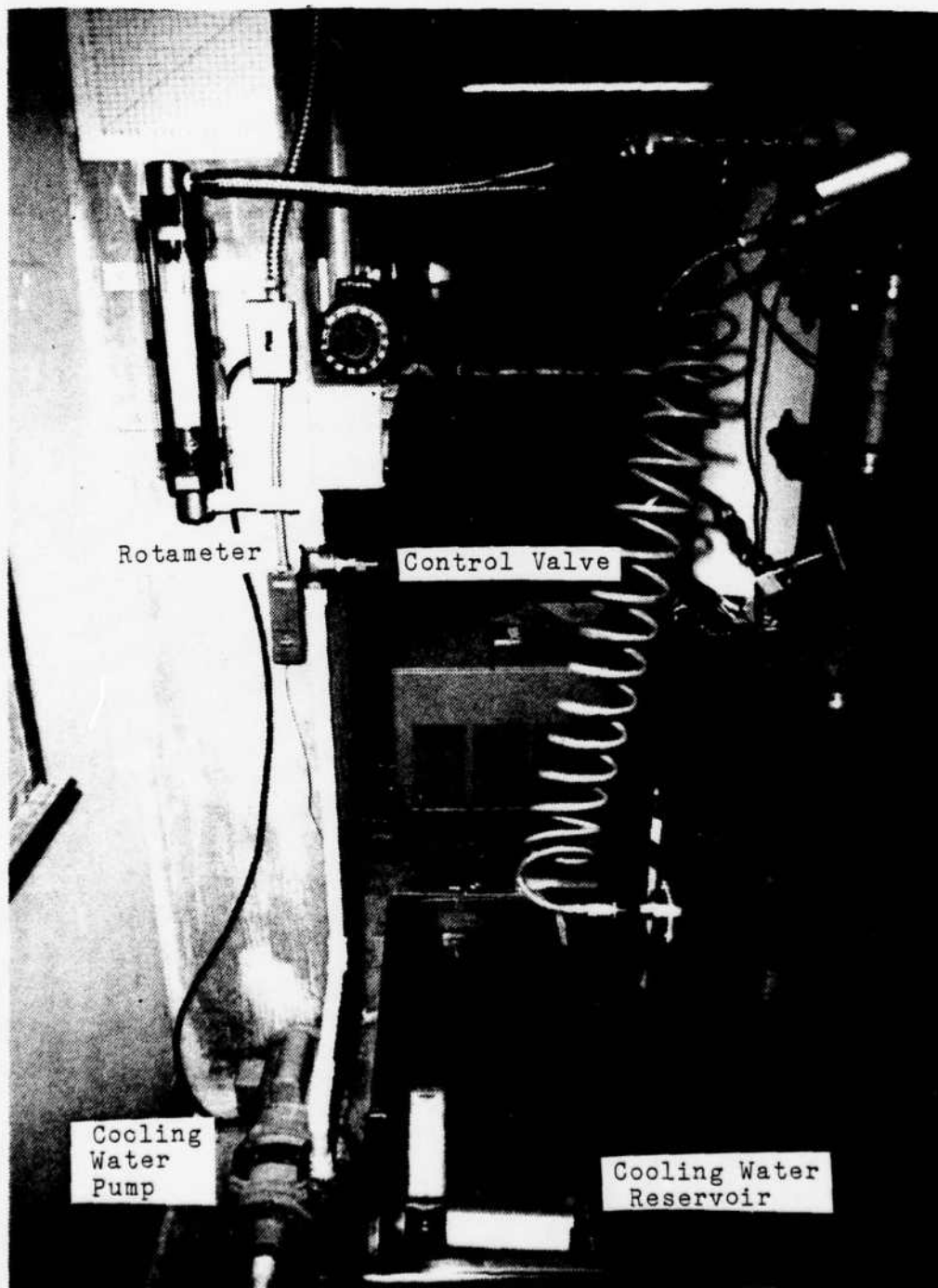


Figure 2.6 Photograph of Cooling Water System

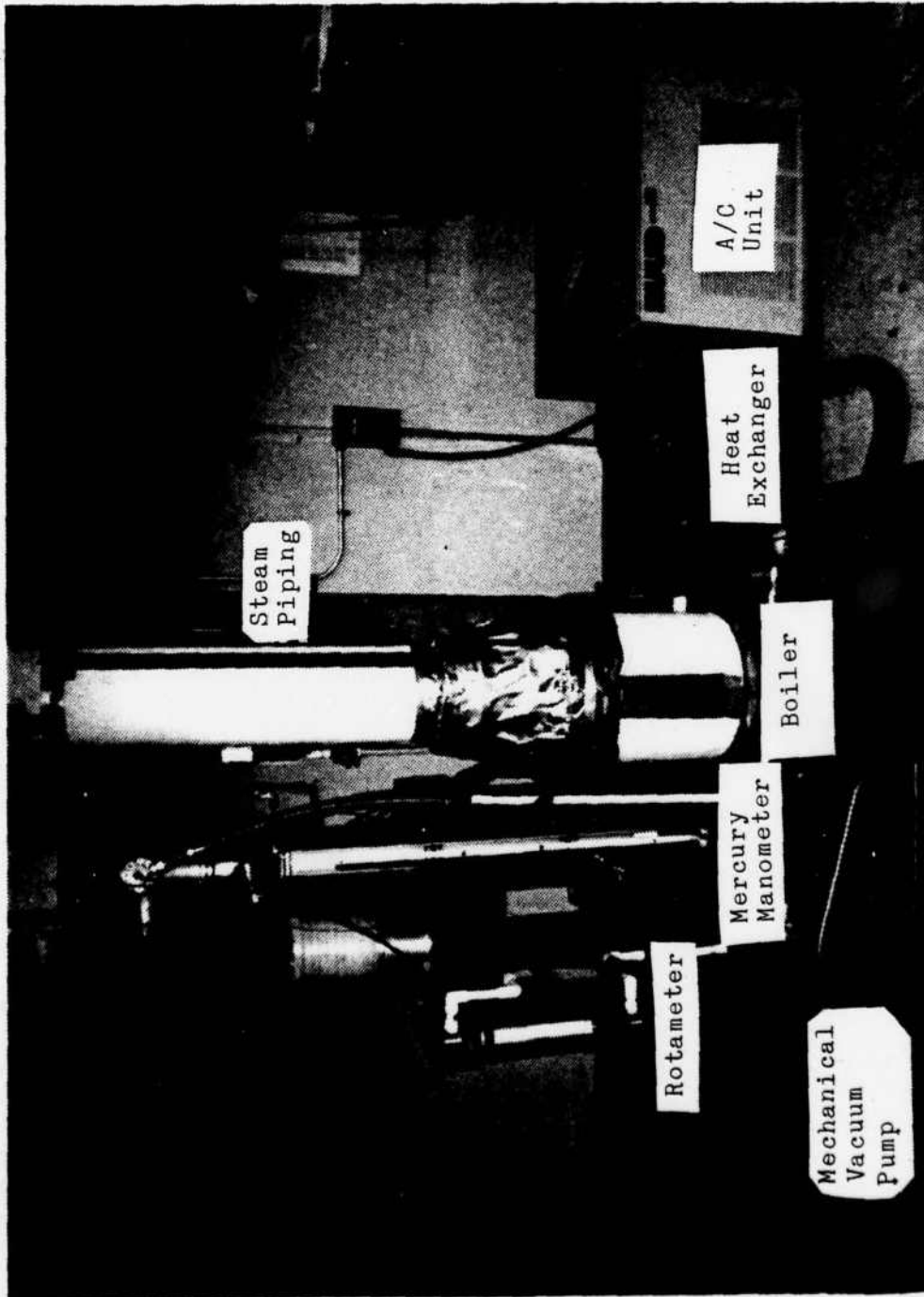


Figure 2.7 Photograph of Overall System Showing  
Boiler and Air Conditioning Unit



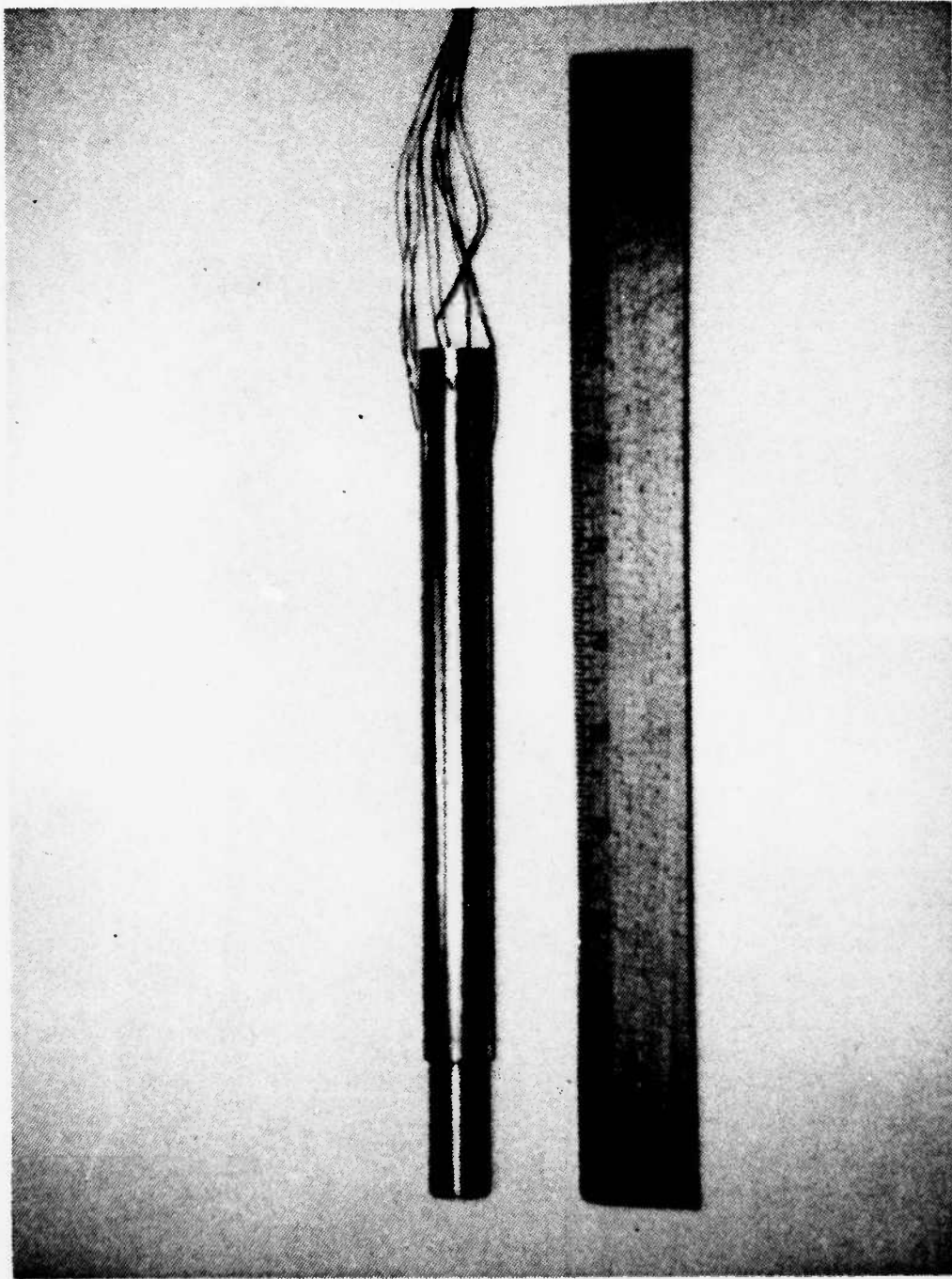


Figure 2.8 Photograph of Instrumented Test Tube

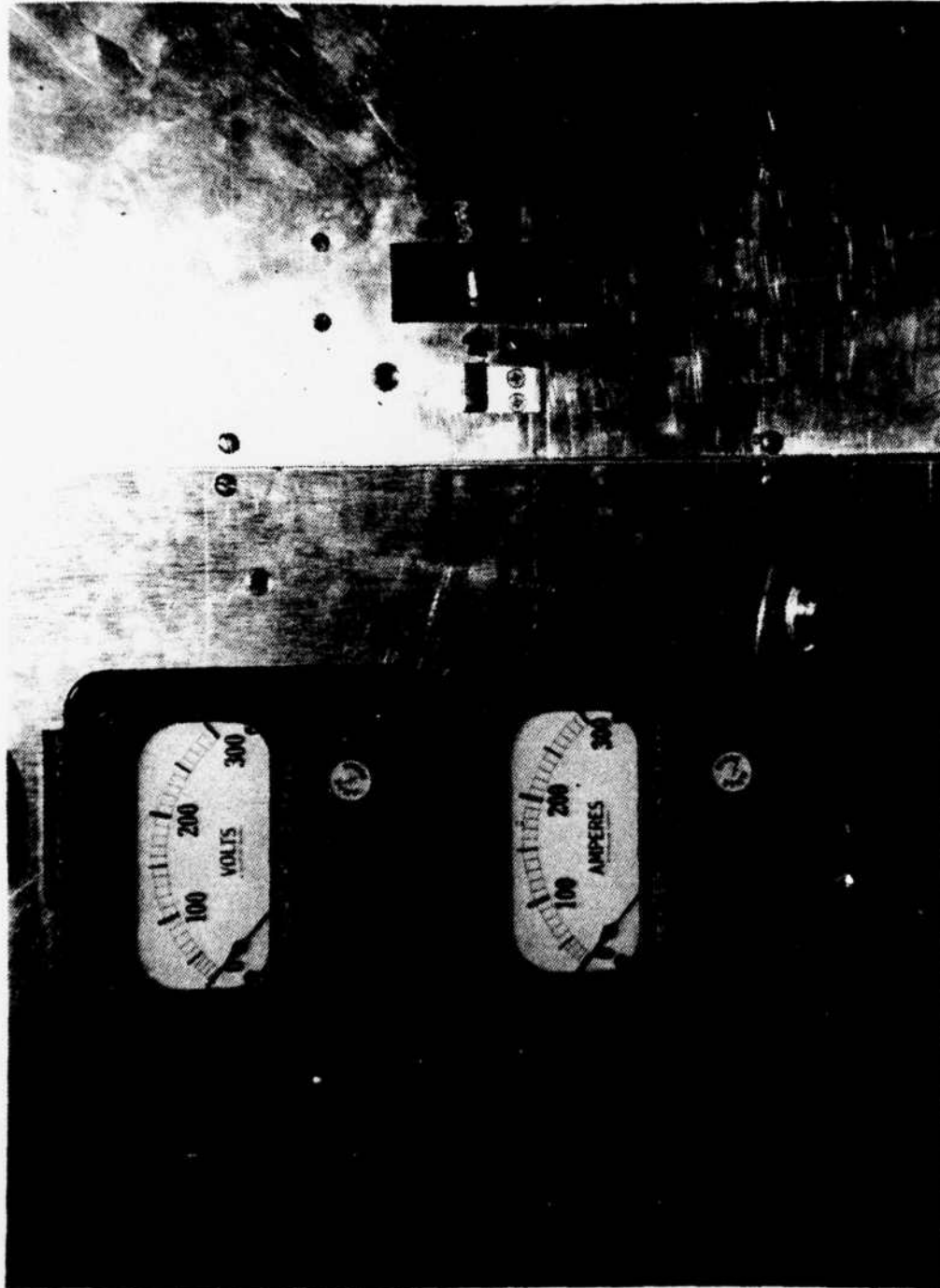


Figure 2.9 Photograph of Control Panel

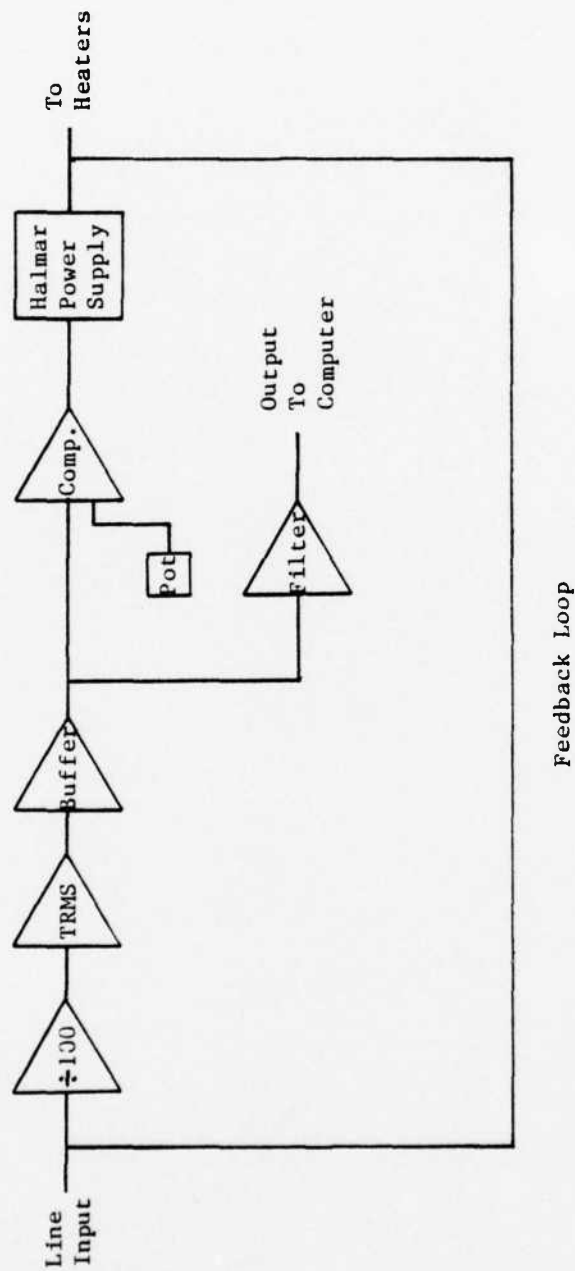


Figure 2.10 Power Controller Circuitry

### III. SYSTEM OPERATION

After a thorough cleaning using the procedures described in Appendix F, a test tube may be installed by the steps outlined in Appendix D. Each system start-up should be accomplished by the procedures described in Appendix B. Once the system has reached steady-state conditions (about 30 minutes), data taking for a given test tube may commence. During each data run, a frequent check of the test tube should be made to ensure the desired condensation mode: either dropwise or filmwise. When the tube cleaning procedures of Appendix F are utilized, filmwise condensation conditions will last for about four hours, followed by mixed filmwise and dropwise conditions. Each data set consisted of eight cooling water velocities ranging from 1.37 m/s to 3.84 m/s through the test section. At a given velocity setting, the flow was allowed to steady out for two minutes before recording temperatures. The computer signalled by both audio and visual means when the system was ready for a new data point. An entire data set was recorded in 40 minutes.

#### IV. DATA ACQUISITION/REDUCTION

##### A. DATA ACQUISITION AND STORAGE

A Hewlett-Packard (HP) 3054A automatic data acquisition/control system was used to monitor temperatures from the thermocouples and the quartz crystal thermometers. Figure 4.1 shows a photograph of the system. This system included an HP 3497A data acquisition/control scanner and an HP 3456A digital voltmeter with a resolution of 100-nanovolts. An HP 9826A computer, interfaced with the data acquisition/control system, was used as a controlling unit and provided storage for data. Information was entered through the keyboard to prompt the data acquisition/control unit to automatically scan each channel. Channel assignments are listed in Table 1. These raw data were then transferred to a computer disk under a user-specified file name for later reduction to usable form. The ability to store raw data directly enabled these data to be reduced at any time and allowed flexibility for changes to data-reduction software.

##### B. DATA REDUCTION

Following data acquisition for each data point, results were computed according to the stepwise procedure outlined in the next section, and were then printed on an HP 6771G thermal printer. Appendix G shows an example of a representative data run. Results were also stored in a user-specified plot data file for subsequent plotting using the program PLOT.

## C. STEPWISE SOLUTION PROCEDURE

### 1. Program SIEDER

- a. Compute average cooling water temperature.
- b. Compute average wall temperature.
- c. Compute cooling water velocity.
- d. Compute mass flow rate of cooling water.
- e. Compute heat transferred to cooling water.
- f. Compute average inside wall temperature.
- g. Compute LMTD.
- h. Assume fin efficiency.
- i. Compute inside heat-transfer coefficient.
- j. Compute Nusselt number.
- k. Calculate fin efficiency using previously-calculated, heat-transfer coefficient.

1. Recalculate heat-transfer coefficient.

Recalculate Nusselt number and compare to Nusselt number found in j and iterate if not within 1%. Figure 5.1 shows an example of plotted data and Appendix G shows a listing of PLOT.

### 2. Program NSFDRP

- a. Compute average cooling water temperature.
- b. Compute cooling water velocity.
- c. Compute mass flow rate of cooling water.
- d. Compute heat transferred to cooling water.
- e. Compute log mean temperature difference.
- f. Compute overall heat-transfer coefficient based on outside area.

- g. Compute wall resistance based on outside area.
- h. Compute Reynolds number of cooling water.
- i. Assume fin efficiency.
- j. Compute inside heat-transfer coefficient.
- k. Calculate cooling water temperature rise.
- l. Calculate fin efficiency using previously-calculated, heat-transfer coefficient.
- m. Recalculate heat-transfer coefficient and iterate if not within 1% of the value found in h.
- n. Calculate condensing heat-transfer coefficient from  $U_0$ ,  $R_w$  and  $h_i$ .

TABLE I  
HP 3497A Channel Assignments

<u>Channel</u>	<u>Assignment</u>
20	steam
21	steam
22	condensate
23	room
24	room
25	wall
26	wall
27	wall
28	wall
29	wall
30	wall

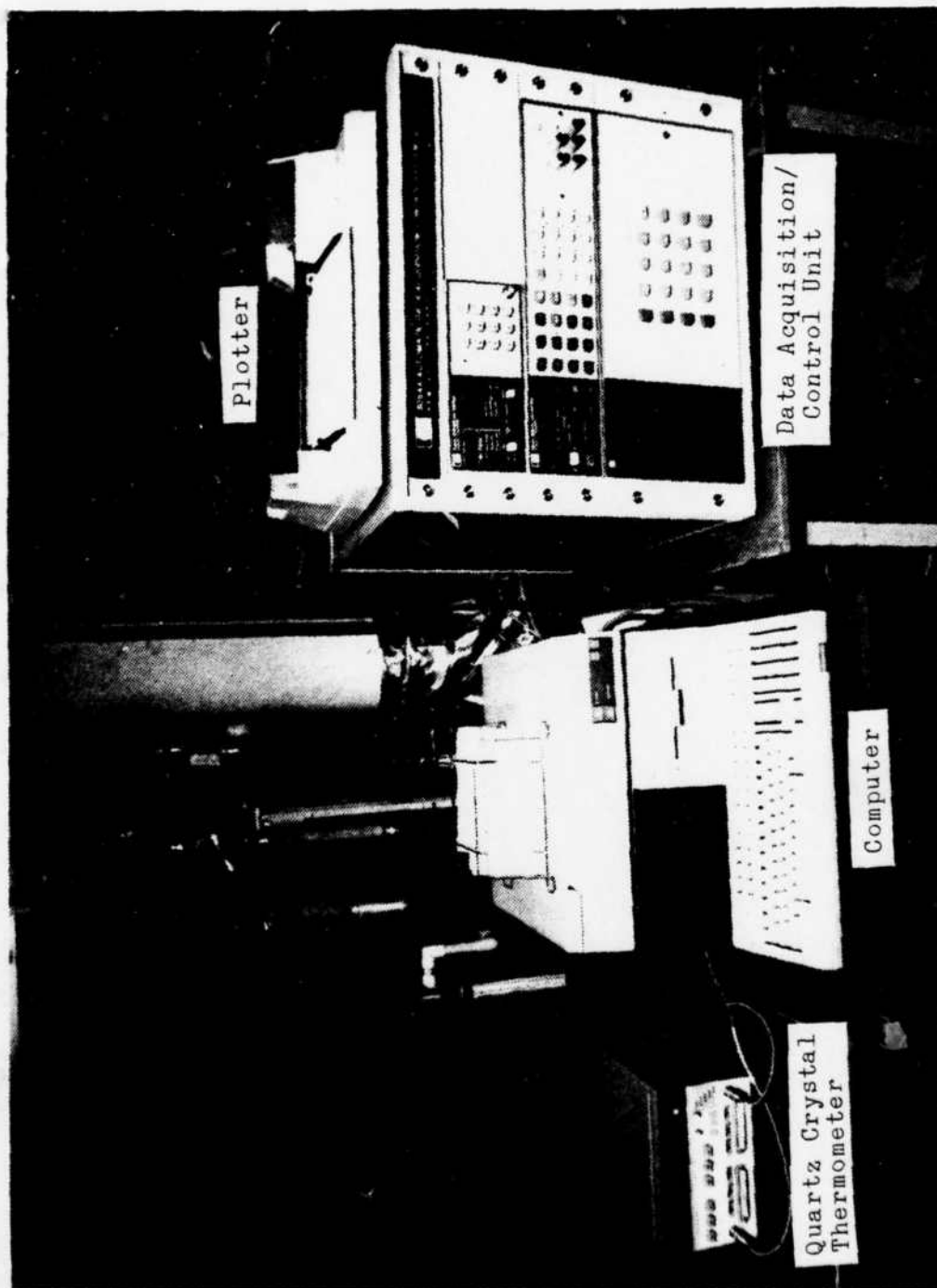


Figure 4.1 Photograph of Data Acquisition/Reduction System



## V. RESULTS AND DISCUSSIONS

### A. INSIDE HEAT-TRANSFER COEFFICIENT

Experimental data were taken at atmospheric pressure by the procedures outlined in Chapter III. Twelve data sets were taken to determine the inside heat-transfer coefficient. The first four data sets were utilized to test the data acquisition/reduction program SIEDER and the middle five data sets experienced mixed filwise and dropwise condensation conditions. Data sets 10-12 showed filmwise condensation throughout each of the data collection sets. Figure 5.1 is a plot of data taken during run number 10. Similar results were obtained for data runs 11-12. The analysis of all data showed a Sieder-Tate coefficient of  $0.029 \pm 0.001$  to be representative for the experimental apparatus (Table II). The Sieder-Tate correlation for fully developed turbulent flow has a leading coefficient of 0.027 (Ref. 16). Rose (Ref. 14) shows a leading coefficient of 0.030 with an L/D ratio of 17, which is in good agreement with the results of this thesis. The L/D ratio for the experimental apparatus used during this thesis was 18, well below that for fully developed flow (Ref. 16); therefore the inside heat-transfer coefficient was correspondingly higher.

TABLE II  
Sieder-Tate Coefficients

File	Ci
10	.0291
11	.0287
12	.0287

#### B. OUTSIDE HEAT-TRANSFER COEFFICIENT

Experimental data were taken at atmospheric pressure by the procedures outlined in Chapter III. Four data sets were recorded to determine the outside heat-transfer coefficient using the program NSFDRP (Appendix G) to reduce the raw data. Figure 5.2 shows a plot of the four data sets along with a curve showing the corresponding Nusselt prediction. All of the data lie above the theoretical curve. This discrepancy has two possible explanations. Either dropwise condensation and/or vapor shear associated with a vapor velocity of 3 m/s could increase the condensation heat transfer coefficient. The effect of vapor shear has been studied by many investigators including Rose as described in a very recent report {Ref. 18}. Rose reported that when vapor velocity was increased to 7 m/s for refrigerant-113, the condensing coefficient increased by 20%. The presence of dropwise condensation significantly raises the heat-transfer coefficient, sometimes as much as ten times {Ref. 17}.

A large amount of scatter occurred in the recorded data. This situation could have occurred due to noncondensable gases and the inability to regulate system pressure. During normal operation, the Mechanical Engineering Department air compressor (160 psi) was used to operate the air ejector. During the condensation heat transfer coefficient runs, this air compressor was inoperative; therefore, house air (50 psi) was used. This source of air had a very low capacity and fluctuated greatly during each data run, perhaps causing varying amounts of air to be in the vicinity of the test tube.

Due to limited and lack of reliable data, very little can be concluded for the results thus far for the condensing coefficient. More data is necessary to reach any final conclusions.

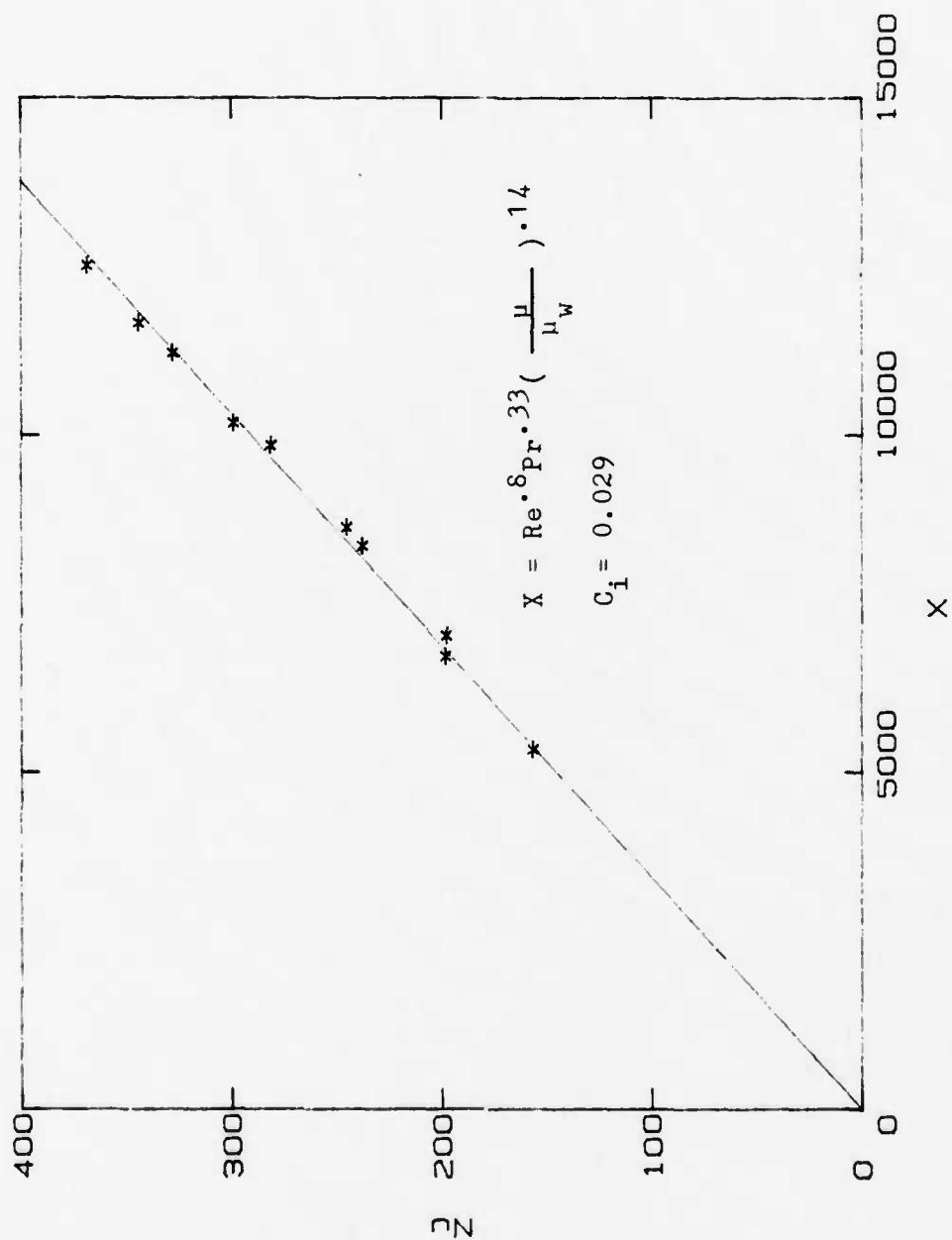


Figure 5.1 Sieder-Tate Parameter Plot

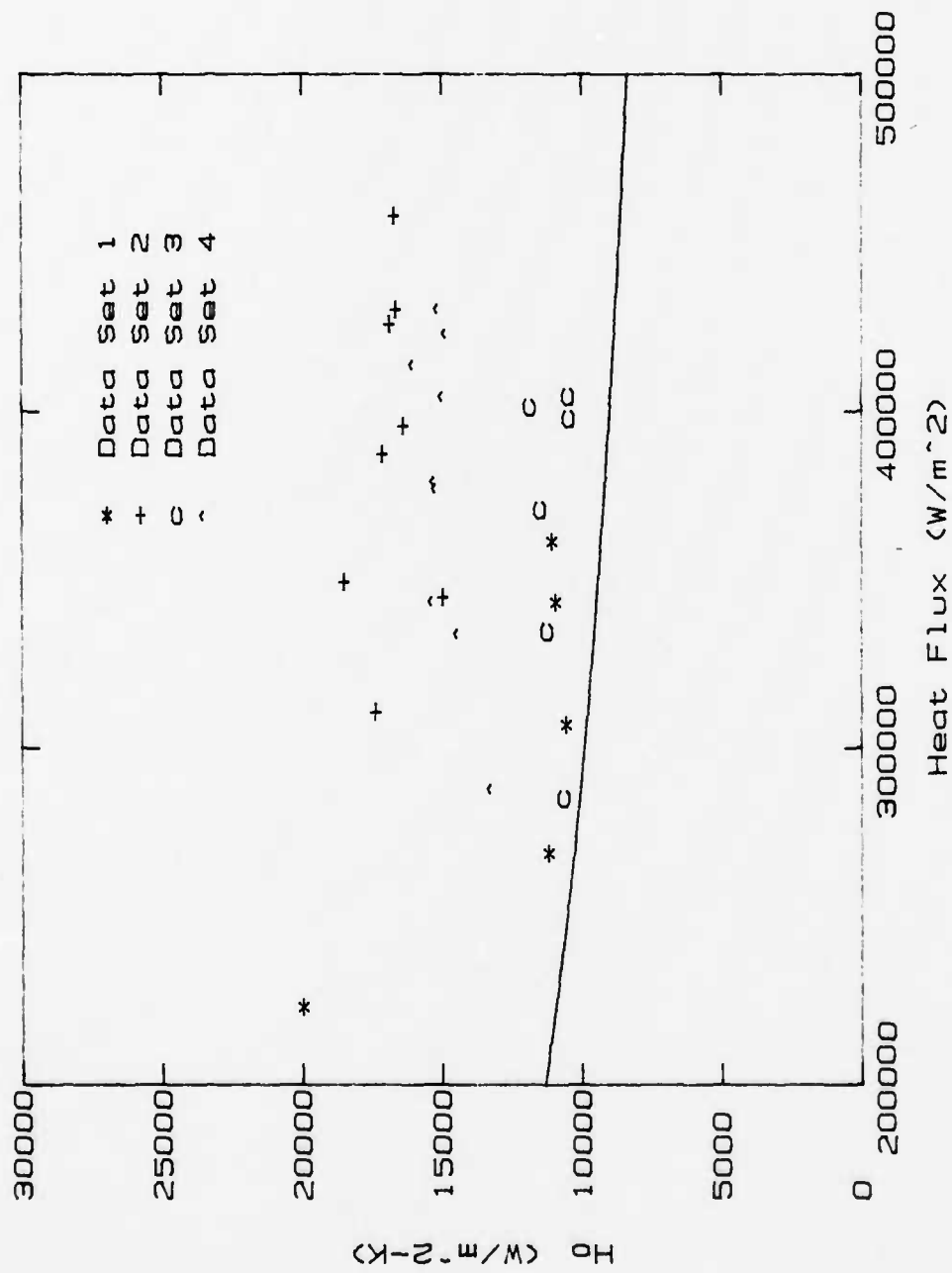


Figure 5.2 Condensing Coefficient Plot

## VI. CONCLUSIONS AND RECOMMENDATIONS

### A. CONCLUSIONS

1. An experimental apparatus that allows the study of condensation heat transfer of steam on a single, horizontal tube has been designed, constructed and instrumented.
2. The water-side heat-transfer coefficient was established using the Sieder-Tate correlation with a leading coefficient of  $0.029 \pm 0.001$ .
3. An analysis scheme to establish the condensing heat-transfer coefficient has been outlined, and data acquisition/reduction programs have been written and tested.

### B. RECOMMENDATIONS

1. To prevent leaking, install Swagelok fittings with Teflon ferrules into the dump condenser lines penetrating the stainless base of the dump condenser section.
2. Rig suspension cables to remove the dump condenser section by attaching them in the ceiling using metal studs.
3. Install a thermopile at the outlet of the test condenser tube as a second means of measuring the cooling water temperature rise across the test section.
4. Use a commutating bridge to accurately determine boiler heater resistance over the full range of power settings.

5. Install a nitrogen cold trap on the mechanical vacuum pump.

6. Install a permanent drain line on the cooling water reservoir to replace the temporary siphon tube.

7. Replace the extension wire from the ice bath to the data acquisition system with thermocouple-quality copper wire.

8. After recommendation No. 1 above is completed, check the system for leak tightness under vacuum conditions.

9. Complete experimentation to determine the condensing heat-transfer coefficient at 1 atmosphere as well as under vacuum conditions.

## APPENDIX A

### SAMPLE CALCULATIONS

#### 1. INSIDE HEAT-TRANSFER COEFFICIENT

A set of calculations was performed to verify data reduction program SIEDER. One data point was selected arbitrarily from data set 10.

a. Given the following inlet and outlet temperatures, compute average cooling water temperature.

$$T_1 = 23.94^{\circ}\text{C}$$

$$T_2 = 26.32^{\circ}\text{C}$$

$$T_b = (23.94 + 26.32)/2 = 25.13^{\circ}\text{C}$$

b. Compute average wall temperature.

$$T_w = (T_{w1} + T_{w2} + T_{w3} + T_{w4} + T_{w5} + T_{w6})/6 = 62.64^{\circ}\text{C}$$

c. Compute water velocity.

Flow meter reading = 25% and from the calibration curve,  $V_w = 4.5 \text{ ft/s}$  or  $V_w = 1.37 \text{ m/s}$ .

From Reference 16, Table A.6 at 300 K the following properties are found:

$$Pr = 5.83$$

$$\mu_f = 855\text{E-}6 \text{ N-s/m}^2$$

$$C_p = 4.179 \text{ kJ/Kg-K}$$

$$K_f = 613\text{E-}3 \text{ W/m-K}$$

$$\nu_f = 1.003\text{E-}3 \text{ m}^3/\text{kg}$$

d. Compute mass flow rate of cooling water.

$$A = \pi D_i^2/4$$

$$\dot{m} = V_w A/\nu = 0.173 \text{ kg/s}$$



e. Compute heat transferred to cooling water.

$$Q = \dot{m} C_p (T_1 - T_2)$$

$$Q = 1721 \text{ W}$$

f. Compute average inside wall temperature.

$$T_w = Q \ln (D_o/D_i) / 2 \pi k_f L \quad \text{Reference 17}$$

$$T_w = 2.16^\circ\text{C}$$

$$T_{wi} = T_w - 0.5 \Delta T_w$$

$$T_{wi} = 61.56^\circ\text{C}$$

g. Compute log mean temperature difference.

$$\text{LMTD} = (T_2 - T_1) / \ln [(T_{wi} - T_1) / (T_{wi} - T_2)]$$

h. A fin efficiency is assumed to be 20% for first interaction.

i. Compute heat-transfer coefficient.

$$h_i = Q / \pi D_i (L + L_1 \eta_1 + L_2 \eta_2) \text{ LMTD}$$

$$h_i = 7772 \text{ W/m}^2\text{-K}$$

j. Compute Nusselt number.

$$\text{Nu} = h_i D_i / k_f$$

$$\text{Nu} = 161 \text{ ----- first iteration}$$

k. Calculate fin efficiency.

$$P_1 = 2\pi D_o = 0.1197 \text{ m}$$

$$P_2 = 2\pi D_r = 0.100 \text{ m}$$

$$A_1 = \pi D_o (D_o - D_i) = 0.00038 \text{ m}^2$$

$$A_2 = \pi D_r (D_r - D_i) = 1.6 \text{ E-4 m}^2$$

$$m_1 = \sqrt{h_i P_1 / k_f A_1}$$

$$m_1 = 79.74$$

$$m_2 = \sqrt{h_i P_2 / k_f A_2}$$

$$m_2 = 112.32$$

$$\eta_1 = \tanh (m_1 L_1)/m_1 L_1$$

$$\eta_1 = .2079$$

$$\eta_2 = .2913$$

l. Recalculate heat-transfer coefficient.

$$h_i = 7589.9 \text{ W/m}^2\text{-K}$$

m. Recalculate Nusselt number and compare to previous calculated value.

$$Nu = 157.24$$

This value for the Nusselt number agrees within 0.3% of the computer generated value ( $Nu_c = 156.7$ ).

## 2. CONDENSATION HEAT-TRANSFER COEFFICIENT

A set of calculations was performed to verify the data reduction program NSFDRP. One data point was selected from data run 1.

a. Given the following inlet and outlet cooling water temperatures, compute average water temperature.

$$T_1 = 30.06^\circ\text{C}$$

$$T_2 = 32.53^\circ\text{C}$$

$$\bar{T}_b = (T_1 + T_2)/2 = 31.3^\circ\text{C}$$

$$T_s = 96.7^\circ\text{C}$$

b. Compute water velocity.

Flow meter reading = 30% and from the calibration curve

$$V_w = 1.64 \text{ m/s}$$

c. Compute mass flow rate of cooling water.

From Reference 16, Table A.6 at 304K the following properties are found:

$$Pr = 5.29$$

$$\mu = 0.781 \text{ E-3 N-s/m}^2$$

$$C_p = 4.178 \text{ kJ/kg-K}$$

$$k = 0.62 \text{ W/m-K } v_w = 1.005 \text{ E-3 m}^3/\text{kg}$$

$$A = \pi D_i^2 / 4$$

$$A = 1.267 \text{ E-4 m}^2$$

$$\dot{m} = V_w A / v$$

$$\dot{m} = .2067 \text{ kg/s}$$

d. Compute heat transferred to cooling water.

$$Q = 2133 \text{ W}$$

e. Compute LMTD.

$$LMTD = (T_2 - T_1) / \ln [(T_s - T_1) / (T_s - T_2)]$$

$$LMTD = 65.40^\circ\text{C}$$

f. Compute overall heat-transfer coefficient based on outside area.

$$A_o = \pi D_o L$$

$$U_o = Q / A_o LMTD$$

$$U_o = 4086.71 \text{ W/m}^2\text{-K}$$

g. Compute wall resistance based on outside area.

$$R_m = D_o \ln(D_o / D_i) / 2 k_{cu}$$

$$R_m = 1.003 \text{ E-5 m}^2\text{-K/W}$$

h. Compute Reynolds number of cooling water.

$$Re_w = V_w D_i / \nu_f$$

$$Re_w = 26535$$

i. Assume fin efficiencies of  $\eta_1 = 0.20$  and  $\eta_2 = 0.24$  and assuming  $(\mu/\mu_w)^{0.14} = 1.0$

j. Compute inside heat-transfer coefficient.

$$h_i = (k_w C_i / D_i) Re_w^{.8} Pr^{.333} (\mu/\mu_w)^{.14}$$

$$h_i = 8533.72 \text{ W/m}^2\text{-K}$$

k. Calculate fin efficiency using previously-calculated heat-transfer coefficient from j.

$$m_1 = 83.56 \text{ m}^{-1}$$

$$m_2 = 117.70 \text{ m}^{-1}$$

$$\eta_1 = 0.20$$

$$\eta_2 = 0.24$$

l. Calculate cooling water rise.

$$\bar{T}_w = T_b + \Delta T_w = 72^\circ\text{C}$$

From Reference 16 at 345 K,  $\nu_w = 389\text{E-6 N-S/m}^2$

$$(\mu/\mu_w)^{0.14} = 1.1$$

m. Recalculate heat transfer coefficient and iterate if not within 1% of the value found in j.

$$h_i = 9387 \text{ W/m}^2\text{-K}$$

n. Calculate condensation heat-transfer coefficient.

$$h_o = \frac{1}{\frac{1}{U_o} - \frac{\frac{D_o L}{D_i (L + \eta_1 L_1 + \eta_2 L_2) h_i} - R_m}}$$

$$h_o = 10405 \text{ W/m}^2\text{-K}$$

This value for the condensation heat-transfer coefficient agrees within 1% of the computer generated value ( $h_{oc} = 10550$ ).

## APPENDIX B

### SYSTEM STARTUP PROCEDURES

1. Familiarize all valve numbers by referring to Figure 2.1.
2. Fill boiler with distilled water to a level 4 inches below top of sight glass.
  - a. Start vacuum pump or air ejector.
  - b. Open suction line supply valve (3).
  - c. Allow vacuum pump/air ejector to run until 15 inches Hg of vacuum is attained.
  - d. Close suction line supply valve (3).
  - e. Shut down vacuum system.
  - f. Open discharge on distilled water tank.
  - g. Open distilled water supply line valve (6).
  - h. Close distilled water supply line valve (6) when boiler is filled to 4 inches below the top of the sight glass.
3. For vacuum operations, start vacuum pump/air ejector then open suction line supply valve (3) until desired pressure is reached. Suction line supply valve may be throttled to maintain pressure.
4. Energize viewing window heater and adjust rheostat to 110. Open air supply valve (9) about  $\frac{1}{2}$  turn. The air supply may require further adjustments to keep viewing window clear.
5. Open dump condenser supply valve (2) fully.

6. Fill cooling water reservoir.
  - a. Open reservoir stop valve (10).
  - b. Open test section throttle valve (11).
  - c. Open reservoir fill valve and allow tank to fill to about 101.6 mm (4 in) from the top.
  - d. Close reservoir stop valve.
  - e. Energize cooling water circulation pump. The switch is located above the pump.
7. Shut the following power supply breakers:
  - a. Panel p-5 switch 3.
  - b. Switch 3 on side of control panel.
  - c. Switch 1 on front panel.
8. Increase boiler heater voltage to a maximum of 200 volts during warmup; about 15 minutes. When operating under vacuum conditions use a lower voltage to limit vibration of glass piping.
9. As steam is generated, air is expelled through a relief valve. System pressure should never be allowed to exceed 10 psig.
10. Once steam reaches condenser test section (about 30 minutes following startup), full power operation may begin.
11. The apparatus should be allowed to steam for 30 minutes prior to taking any data.

## APPENDIX C

### SYSTEM SHUTDOWN PROCEDURES

1. Decrease boiler heater voltage to zero.
2. Open all three circuit breakers.
3. Secure view window heater rheostat switch; allow air to flow for about 15 minutes longer.
4. Secure cooling water circulation pump.
5. Close cooling water throttle valve.
6. Close dump condenser supply valve.
7. If in use, secure vacuum suction supply valve followed by vacuum pump/air ejector.
8. For cleaning purposes only, the boiler may be drained by unscrewing the Swaglok nut housing the condensate return thermocouple. The Teflon ferrules require only hand tightening.

## APPENDIX D

### TEST SECTION INSTALLATION PROCEDURES

1. Install outlet nylon holder, mixing chamber and return line onto provide 6.35 mm (0.25 in) diameter bolts and tighten.
2. Place clean test tube into inlet nylon holder and carefully slide holder and test tube into condenser test section snugly.
3. Align test tube to have one thermocouple channel vertical.
4. Carefully slide thermocouples into channels.
5. Ensure wires are straight and lined up with markings on inlet nylon holder and tape into place.
6. Position nylon thermocouple wire retainer over wires.
7. Place inlet nylon holder over end of test tube and tighten all bolts.
8. Energize circulation pump and check for leakage around connections both inside and outside test section.



APPENDIX E  
THERMOCOUPLE CALIBRATION

1. EQUIPMENT USED

a. Thermocouple wire

Copper-constantan, 0.245 mm (0.01 in) Teflon coated wire was used for all thermocouples. (Omega Catalogue)

b. Calibration bath

A Rosemount Engineering Co. Model 913A calibration bath shown schematically in Figure A.1 was used.

- 1) Heating: Electrical
- 2) Cooling: Liquid Nitrogen

Note:

Once a desired temperature is reached, the temperature is held constant by rapid cycling between heating and cooling. The manufacturer rates the temperature bath fluctuation to be less than  $0.01^{\circ}\text{C}$ . Observations during the calibration procedure showed bath temperature fluctuation to be less than  $0.025^{\circ}\text{C}$  ( $1.0\mu\text{V}$ ).

c. Thermocouple readout

An HP 3054A Automatic Data Acquisition/Control System with resolution of  $0.1\mu\text{V}$  was used to obtain data.

d. Reference Point

A reference junction was placed in a 0.15 m Dia X 0.28 m high Thermos flask filled with finely-crushed ice.

e. Temperature measurement

Mercury-in-glass thermometers with a resolution of  $0.1^{\circ}\text{C}$  were used. A total of four thermometers were used with the following ranges: 0-25, 25-54, 50-76 and  $76-104^{\circ}\text{C}$ .

2. PREPARATION

a. Procedure

Two thermocouples were prepared, one at the beginning and the other at the end of a reel of thermocouple wire, using the following procedure:

- 1) The Teflon insulation was removed for a length of about 4 mm from one end of a 2 m long piece of wire and a thermocouple bead was made using a Dynatech Corporation thermocouple welder.
- 2) The other end of the thermocouple wire was soft soldered to a pair of heavy duty copper wires.
- 3) Heat shrink insulation was placed on the soldered end.

b. Reference point

The thermocouple reference junctions were placed in a 5 cm test tube and then into a thermos flask containing finely crushed ice as shown in Figure A.1.

c. Thermometers

Thermometers were completely immersed in the calibration bath as recommended by the manufacturer.

d. Analysis

A short computer program (TC\_CAL) was written to accept the thermocouple readings through the HP data acquisition

system, and the bath temperature through the keyboard. This program prints all data as well as stores the data on a computer disk. A listing of the computer program is provided in Appendix G.

### 3. CALIBRATION PROCEDURE

- a. The bath temperature was set at about 15°C.
- b. A constant temperature is reached when rapid cycling of heating and cooling occurs, but wait three minutes to enter data.
- c. Enter the bath temperatures, as measured by the mercury-in-glass thermometer, into the keyboard. Immediately following the data entry, the computer will read the thermocouple EMF automatically and print the bath temperature and thermocouple EMF ( $\mu V$ ).
- d. When the computer prompts for more data, increase bath temperature by about 10°C and repeat the above procedure up to about 95°C.
- e. Repeat the above procedure for decreasing temperatures.

### 4. CALIBRATION CURVE

- a. A least-squares technique was used to generate a third order polynomial in the form of:

$$T = a_1 E + a_2 E^2 + a_3 E^3$$

T is the temperature in degrees celsius and E is the thermocouple reading in microvolts.

- b. Values generated for the coefficients are:

$$a_1 = 0.02635$$

$$a_2 = -9.735 \text{ E-7}$$

$$a_3 = 6.577 \text{ E-11}$$

c. Figure A.2 is a sample printout of calibration data.

d. Figure A.3 is a graphical representation of calibration data.

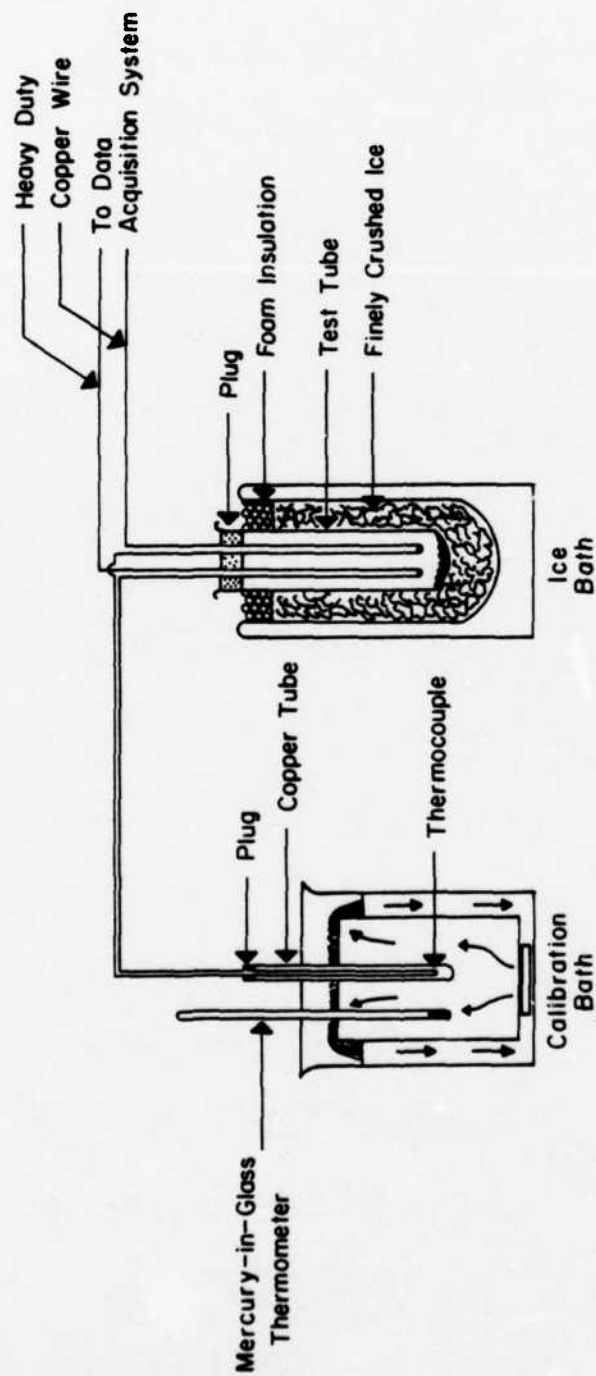


Figure E.1 Schematic of Calibration Bath.

Month, date and time:03:16:20:20:30

Bath Temp (Deg C)	Enf(0) (Micro V)	Enf(1) (Micro V)
13.06	503.0	503.2
24.33	955.0	956.0
35.33	1409.5	1409.0
46.72	1889.8	1891.1
59.50	2442.9	2442.4
72.06	2996.4	2995.7
84.78	3575.8	3575.1
94.00	3998.8	3998.1
93.22	3963.9	3963.0
82.89	3488.8	3488.2
66.89	2767.8	2766.9
54.33	2216.9	2215.8
42.06	1691.7	1690.9
30.67	1213.4	1212.4
20.72	806.5	806.0
13.06	502.5	502.0

16 runs were stored in file CAL\_DATA

Figure E.2 Calibration Printout.

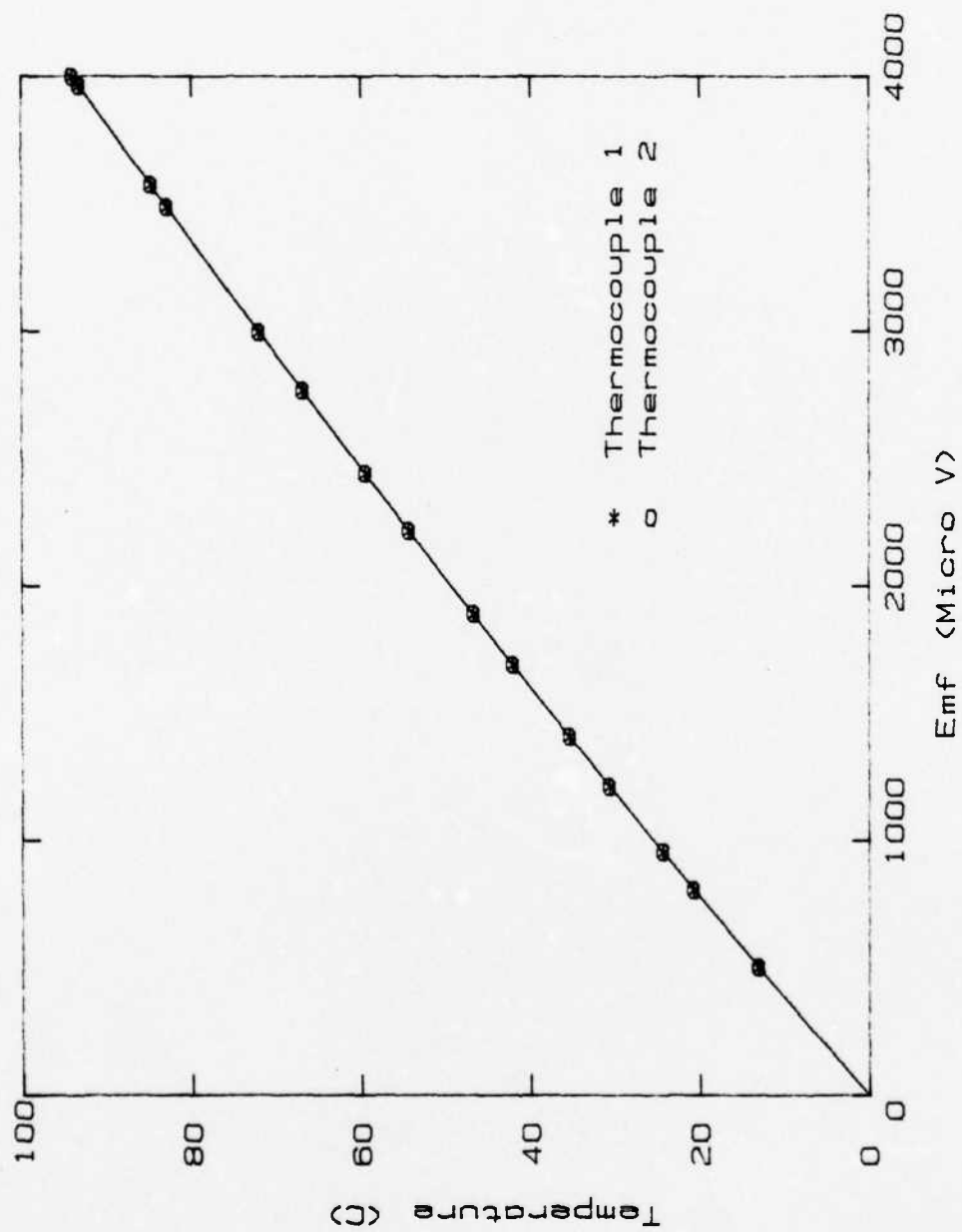


Figure E.3 Thermocouple Calibration Curve.

## APPENDIX F

### TEST TUBE CLEANING PROCEDURES

----Caution----

The following mixture is highly toxic and very irritant when contacted by the skin. Be very careful not to splash the solution in any way. Wear protective gloves and eye protection when the actual cleaning is being conducted.

1. Ensure the surface of the tube is smooth by placing in lathe and polishing with copper cleaner (Brasso) and a clean rag.

2. While still in the lathe, wipe completely with acetone followed by ethyl alcohol.

3. Prepare a solution of equal parts of 50% sodium hydroxide solution (commercially prepared, available through MCB Manufacturing Chemists Inc., Cincinnati, OH) and ethyl alcohol. About 4 ounces each mixed in a shallow stainless-steel pan is sufficient. The sodium hydroxide will precipitate out of solution and form a white paste.

4. Heat the mixture to about 80°C, but try to avoid spattering. The white pasty texture of the solution should now dissolve into a clear liquid.

5. Completely immerse the tube into the mixture and scrub the entire surface with a bristle brush (old tooth-brushes work fine).

6. Rinse with tap water followed by distilled water.



7. Allow the tube to remain in distilled water until ready for installation.

8. The nylon holders should also be cleaned with the mixture.

9. The test tube should be installed as soon as possible after cleaning.

APPENDIX G  
COMPUTER PROGRAM LISTINGS

```
100! FILE NAME: TC_CAL
110! REVISED: June 1. 1983
120!
130 DIM Emf(I)
140 PRINTER IS 701
150 BEEP
160 INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Date$
170 OUTPUT 709:"TD":Date$
180 OUTPUT 709:"TD"
190 ENTER 709:Date$
200 PRINT USING "12X, ""Month, date and time: """,14A":Date$
210 BEEP
220 INPUT "GIVE A NAME FOR DATA FILE",D_files$
230 CREATE BDAT D_files$.5
240 ASSIGN @File TO D_files$
250 J=0
260 PRINT " "
270 PRINT USING "12X, ""Bath Temp      Emf(0)      Emf(1) """,
280 PRINT USING "12X, "" (Deg C)      (Micro V)      (Micro V) """,
290 Repeat: !
300 BEEP
310 INPUT "ENTER BATH TEMPERATURE (DEG F)",T_bath
320 T_bath=(T_bath-32.)/1.8
330 OUTPUT 709:"AR AF20 AL21"
340 OUTPUT 722:"F1 R1 T1 Z1 FL1"
350 FOR I=0 TO 1
360 OUTPUT 709:"AS SA"
370 ENTER 722:Emf(I)
380 Emf(I)=ABS(Emf(I))*10^6
390 NEXT I
400 PRINT USING "13X,3D,DD,7X,4D,D,5X,4D,D":T_bath,Emf(*)
410 OUTPUT @File;T_bath,Emf(*)
420 BEEP
430 INPUT "ARE YOU TAKING MORE DATA (1=YES,0=NO)?",Go_on
440 J=J+1
450 IF Go_on=1 THEN Repeat
460 BEEP
470 PRINT " "
480 PRINT USING "12X,DD, "" runs were stored in file """,10A":J,D_files$
490 END
```

```

1000! FILE NAME: NSFDRP
1010 !REVISED: 23 MAY 1983
1020 DIM Emf(10)
1030 D1=.0127
1040 Do=.01905
1050 Dr=.015875
1060 Dssp=.1524
1070 Ax=PI*Dssp`2/4-PI*Do*L ! TO BE MODIFIED
1080 L=.13335
1090 L1=.060325
1100 L2=.034925
1110 L1=L1+(Do-D1)/4
1120 L2=L2+(Dr-D1)/4
1130 C1=.029
1140 Kcu=385.
1150 Rm=Do*LOG(Do/D1)/(2*Kcu)
1160 PRINTER IS 701
1170 CLEAR 709
1180 BEEP
1190 INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)".Date$
1200 OUTPUT 709:"TD":Date$
1210 OUTPUT 709:"TD"
1220 ENTER 709:Date$
1230 PRINT "          Month, date and time :":Date$
1240 BEEP
1250 INPUT "ENTER INPUT MODE (1=3054A,2=FILE)".Im
1260 IF Im=1 THEN
1270 BEEP
1280 INPUT "GIVE A NAME FOR THE RAW DATA FILE".D_files$
1290 CREATE BDAT D_files,10
1300 ELSE
1310 BEEP
1320 INPUT "GIVE THE NAME OF THE EXISTING DATA FILE".D_files$
1330 PRINT " "
1340 PRINT USING "12X.""The following analysis was performed for data in file "
".10A":D_files$
1350 BEEP
1360 INPUT "ENTER THE NUMBER OF RUNS STORED".Nrun
1370 END IF
1380 BEEP
1390 INPUT "GIVE A NAME FOR PLOT DATA FILE".P_files$
1400 CREATE BDAT P_files,5
1410 ASSIGN @File TO D_files$
1420 ASSIGN @Filep TO P_files$
1430 J=0
1440 Repeat:
1450 J=J+1
1460 IF Im=1 THEN
1470 BEEP
1480 INPUT "ENTER FLOWMETER READING".Fm
1490 OUTPUT 709:"AR AF20 AL30"
1500 OUTPUT 722:"F1 R1 T1 Z1 FL1"
1510 OUTPUT 709:"AS SA"
1520 ENTER 722:Dpv
1530 FOR I=0 TO 10
1540 OUTPUT 709:"AS SA"
1550 IF I>4 THEN
1560 Se=0
1570 FOR K=0 TO 10

```

```

1580 ENTER 722;E
1590 Se=Se+E
1600 NEXT K
1610 Emf(I)=ABS(Se/10)*1.E+6
1620 ELSE
1630 ENTER 722;E
1640 Emf(I)=ABS(E)*1.E+6
1650 END IF
1660 NEXT I
1670 ENTER 722;Emf(I)
1680 OUTPUT 713:"T1R2E"
1690 WAIT 2
1700 ENTER 713;T1
1710 OUTPUT 713:"T2R2E"
1720 WAIT 2
1730 ENTER 713;T2
1740 IF J=1 THEN
1750 BEEP
1760 INPUT "ENTER MANOMETER READING (mm Hg)".Phg
1770 BEEP
1780 INPUT "ENTER HEIGHT OF MANOMETER WATER COLUMN".Pwater
1790 END IF
1800 ELSE
1810 ENTER @File;Emf(*),Fm,T1,T2,Phg,Pwater,Bpv
1820 END IF
1830 Tsteam=0
1840 FOR I=0 TO 1
1850 Tsteam=Tsteam+.5*FNTvsv(Emf(I))
1860 NEXT I
1870 Twm=0.
1880 FOR I=0 TO 5
1890 Tw(I)=FNTvsv(Emf(I+5))
1900 Twm=Twm+Tw(I)
1910 NEXT I
1920 Twm=Twm/6
1930 Tcon=FNTvsv(Emf(10))
1940 Psat=FNpvst(Tsteam)
1950 Ptest=(Phg+Pwater/13.6)*133.322
1960 IF J=1 THEN
1970 Vst=FNvst(Tsteam)
1980 Ppng=(Ptest-Psat)/Ptest
1990 Ppst=1-Ppng
2000 Mfng=Ppng/(287*(Tsteam+273.15)/(Vst*Ptest)+Ppng)
2010 Vfng=Mfng/(1.608-.608*Mfng)
2020 Mfng=Mfng*100
2030 Vfng=Vfng*100
2040 BEEP
2050 PRINT " "
2060 PRINT USING "12X, ""Measured pressure = """,D.3D
E. "" (Pa) """:Ptest
2070 PRINT USING "12X, ""Pressure corresponding to measured steam temp = """,D.3D
E. "" (Pa) """:Psat
2080 PRINT USING "12X, ""Noncondensable gas concentration = """,D.D, "" (
Vol %) """:Vfng
2090 PRINT USING "12X, ""Noncondensable gas concentration = """,DD.D, "" (
Mass %) """:Mfng
2100 IF Mfng>.5 THEN
2110 BEEP
2120 PRINT " "
2130 IF Im=1 THEN

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```

2140 BEEP
2150 PRINT " "
2160 PRINT USING "10X,";"Energize the vacuum system """"
2170 BEEP
2180 INPUT "OK to accept the present run (1=YES,0=NO)?".Ok
2190 IF Ok=0 THEN
2200 BEEP
2210 DISP "NOTE: THE PRESENT DATA RUN WILL BE DISCARDED!! "
2220 WAIT 5
2230 GOTO 1460
2240 END IF
2250 END IF
2260 END IF
2270 END IF
2280 IF Im=1 THEN OUTPUT @File;Emf(*),Fm,T1,T2,Phg,Pwater,Bps
2290: ANALYSIS BEGINS
2300 Tavg=(T1+T2)*.5
2310 Cpw=FNCPw(Tavg)
2320 Rhow=FNRRhow(Tavg)
2330 Mf=Fm*.02451*.3048^3/100
2340 Md=Mf*Rhow
2350 Vw=Mf/(PI*Di^2/4)
2360 Q=Md*Cpw*(T2-T1)
2370 Qp=Q/(PI*Do*L)
2380 Two=Tum+Qp*Rm*.5
2390 Dtf=Tsteam-Two
2400 Kw=FNKw(Tavg)
2410 Muw=FNMuw(Tavg)
2420 Rew=Rhow*Vw*Di/Muw
2430 Prw=FNPrw(Tavg)
2440 Fe1=0.
2450 Fe2=0.
2460 Cf=1.
2470 Hi=Kw*Ci/Di*Rew*.8*Prw*.3333*Cf
2480 Dt=Q/(PI*Di*(L+L1*Fe1+L2*Fe2)*Hi)
2490 Cfc=(Muw/FNMuw(Tavg+Dt))^.14
2500 IF ABS((Cfc-Cf)/Cfc)>.01 THEN
2510 Cf=(Cf+Cfc)*.5
2520 GOTO 2470
2530 END IF
2540 P1=PI*(Di+Do)
2550 A1=(Do-Di)*PI*(Di+Do)*.5
2560 M1=(Hi*P1/(Kcu*A1))^.5
2570 P2=PI*(Di+Dr)
2580 A2=(Dr-Di)*PI*(Di+Dr)*.5
2590 M2=(Hi*P2/(Kcu*A2))^.5
2600 Lmtd=(T2-T1)/LOG((Tsteam-T1)/(Tsteam-T2))
2610 Uo=Q/(Lmtd*PI*Do*L)
2620 Fe1=FNtanh(M1*L1)/(M1*L1)
2630 Fe2=FNtanh(M2*L2)/(M2*L2)
2640 Ho=1/(1/Uo-Do*L/(Di*(L+L1*Fe1+L2*Fe2)*Hi)-Rm)
2650 Dtc=Q/(PI*Di*(L+L1*Fe1+L2*Fe2)*Hi)
2660 IF ABS((Dtc-Dt)/Dtc)>.01 THEN 2470
2670 Troom=FNtvs((Emf(3)+Emf(4))*5)
2680 PRINT "UO=";Uo
2690 Hos=Q/(PI*Do*L*(Tsteam-Two))
2700 PRINT "HO_STAR=";Hos
2710 Hfg=FNHfg(Tsteam)
2720 Tfilm=(Tsteam+Two)*.5
2730 Kf=FNKw(Tfilm)

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2740 Rhof=FNRhow(Tfilm)
2750 Muf=FNMuw(Tfilm)
2760 Hnu=.725*(Kf^3*Rhof^2*9.81*Hfg/(Muf*Do*Dtf))^-.25
2770 Hpq=.651*Kf*(Rhof^2*9.81*Hfg/(Muf*Do*Qp))^-.3333
2780 PRINT " "
2790 PRINT USING "12X, ""Water velocity          = ""'.2,DD, ""' (m/S)""';Vw
2800 PRINT USING "12X, ""Reynolds number          = ""'.5D,D, ""';Rew
2810 PRINT USING "12X, ""Inside heat-tran coef      = ""'.5D,D, ""' (W/m^2-K)""';Hi
2820 PRINT USING "12X, ""Heat flux                  = ""'.2,5DE, ""' (W/m^2)""';Qp
2830 PRINT USING "12X, ""Outside heat-tran coef     = ""'.5D,D, ""' (W/m^2-K)""';Ho
2840 PRINT USING "12X, ""Nusselt coefficient         = ""'.5D,D, ""' (W/m^2-K)""';Hnu
2850 PRINT USING "12X,12X, ""Nus coef (from heat flux) = ""'.5D>D, ""' (W/m^2-K)""';
Hqp
2860 OUTPUT @Filep:Qp,Hos,Hnu
2870 IF Im=1 THEN
2880 BEEP
2890 INPUT "ARE YOU TAKING MORE DATA (1=YES,0=NO)?",Go_on
2900 IF Go_on=1 THEN Repeat
2910 ELSE
2920 IF J<Nrun THEN Repeat
2930 END IF
2940 IF Im=1 THEN
2950 BEEP
2960 PRINT USING "12X, ""NOTE: ""',DD, ""' data runs were stored in file ""'.10A"";J.
D_files
2970 END IF
2980 BEEP
2990 PRINT " "
3000 PRINT USING "12X, ""NOTE: ""',DD, ""'X-Y pairs were stored in plot data file "
".10A"";J.P_files
3010 ASSIGN @File TO *
3020 END
3030 DEF FNPvst(Tsteam)
3040 DIM K(8)
3050 DATA -7.691234564,-26.08023696,-158.1706546,64.23285504,-118.9646225
3060 DATA 4.16711732,20.9750676,1.E9,6
3070 READ K(*)
3080 T=(Tsteam+273.15)/647.3
3090 Sum=0
3100 FOR N=0 TO 4
3110 Sum=Sum+K(N)*(1-T)^(N+1)
3120 NEXT N
3130 Br=Sum/(T*(1+K(5)*(1-T)+K(6)*(1-T)^2)-((1-T)/(K(7)*(1-T)^2+K(8)))
3140 Pr=EXP(Br)
3150 P=22120000*Pr
3160 RETURN P
3170 FNEND
3180 DEF FNHfg(T)
3190 Hfg=2497.7389-T*(2.2074+T*(1.7079E-3-2.8593E-6))
3200 RETURN Hfg*1000
3210 FNEND
3220 DEF FNMuw(T)
3230 Mu=1.57609473E-3-T*(3.51198576E-5-T*(3.5835816E-7-1.365586115E-9*T))
3240 RETURN Mu
3250 FNEND
3260 DEF FNVvst(T)
3270 V=58.4525538-T*(1.51508776-T*(.01372746585-T*4.25366711E-5))
3280 RETURN V
3290 FNEND
3300 DEF FNCpu(T)

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```

3310 Cpw=4.21120858-T*(2.26826E-3-T*(4.42361E-5+2.71428E-7*T))
3320 RETURN Cpw*1000
3330 FNEND
3340 DEF FNRhow(T)
3350 Ro=999.52946+T*(.01269-T*(5.482513E-3-T*1.234147E-5))
3360 RETURN Ro
3370 FNEND
3380 DEF FNPrw(T)
3390 Prw=10^(1.09976605-T*(1.3749326E-2-T*(3.958875E-5-3.45026E-7*T)))
3400 RETURN Prw
3410 FNEND
3420 DEF FNKw(T)
3430 Kw=.5625894+T*(2.2964546E-3-T*(1.509766E-5-4.0581652E-8*T))
3440 RETURN Kw
3450 FNEND
3460 DEF FNTanh(X)
3470 P=EXP(X)
3480 Q=EXP(-X)
3490 Tanh=(P+Q)/(P-Q)
3500 RETURN Tanh
3510 FNEND
3520 DEF FNTvsv(V)
3530 T=V*(.02617334416-V*(9.2447859E-7-V*6.0746642E-11))
3540 RETURN T
3550 FNEND
3560 DEF FNHF(T)
3570 Hf=T*(4.203849-T*(5.88132E-4-T*4.55160317E-6))
3580 RETURN Hf*1000
3590 FNEND

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```

1000! FILE NAME: SIEDER
1010! REVISED: May 23. 1983
1020 DIM Emf(10),Tw(5)
1030 Kcu=385
1040! Assign Geometric Variables
1050!
1060 Di=.0127 !Inside Diameter
1070 Do=.01905 !Outside Diameter
1080 Dr=.015875 !Outlet End Diameter
1090 L=.13335 !Condensing Length
1100 L!=.060325 !Inlet End "fin" Length
1110 L2=.034925 !Outlet End "fin" Length
1120 PRINTER IS 701
1130 BEEP
1140 CLEAR 709
1150 INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Bs
1160 OUTPUT 709;"TD";Bs
1170 Series:!
1180 OUTPUT 709;"TD"
1190 ENTER 709:AS
1200 PRINT USING "12X,.""Month. date and time: ""'.14A";AS
1210 BEEP
1220 INPUT "ENTER INPUT MODE (1=3054A,2=FILE)",Im
1230 IF Im=1 THEN
1240 BEEP
1250 INPUT "PROVIDE NAME FOR THE DATA FILE".D_files$
1260 CREATE BDAT D_files$,10
1270 ELSE
1280 BEEP
1290 INPUT "PROVIDE NAME OF THE DATA FILE".D_files$
1300 BEEP
1310 INPUT "ENTER THE NUMBER OF RUNS STORED",Nrun
1320 PRINT USING "12X,.""The following analysis was performed for data in file "
".10A";D_files$
1330 END IF
1340 BEEP
1350 INPUT "PROVIDE NAME FOR PLOT DATA FILE".Plot$
1360 CREATE BDAT Plot$,5
1370 ASSIGN @File TO D_files$
1380 ASSIGN @Filep TO Plot$
1390 J=0
1400 Sxs=0
1410 Sxy=0
1420 IF Im=1 THEN
1430! READ DATA THROUGH DATA ACQUISITION SYSTEM
1440! IF THE INPUT MODE (Im) = 1
1450 BEEP
1460 INPUT "ENTER FLOWMETER READING",Fm
1470 OUTPUT 709;"AR AF20 AL30"
1480 OUTPUT 722;"F1 R1 T1 Z1 FL1"
1490 FOR I=0 TO 10
1500 OUTPUT 709;"AS SA"
1510 IF I>4 THEN
1520 Se=0

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1530 FOR K=0 TO 9
1540 ENTER 722:E
1550 Se=Se+E
1560 NEXT K
1570 Emf(I)=ABS(Se/10)
1580 ELSE
1590 ENTER 722:E
1600 Emf(I)=ABS(E)
1610 END IF
1620 NEXT I
1630 OUTPUT 713;"T1R2E"
1640 WAIT 2
1650 ENTER 713:T1
1660 OUTPUT 713;"T2R2E"
1670 WAIT 2
1680 ENTER 713:T2
1690 ELSE
1700! READ DATA FROM USER-SPECIFIED FILE IF
1710! INPUT MODE (Im) = 2
1720 ENTER @File;Emf(*),T1,T2,Fm
1730! END IF
1740! Compute Average Bulk Water Temperature
1750 Tavg=(T1+T2)*.5
1760! Compute Average Wall Temperature
1770 Twall=0
1780 FOR I=5 TO 10
1790 Tw(I-5)=FNTvsv(Emf(I))
1800 Twall=Twall+Tw(I-5)
1810 NEXT I
1820 Twall=Twall/6
1830! Compute Thermophysical Properties
1840 Cpw=FNCpw(Tavg)
1850 Rhow=FN Rhow(Tavg)
1860 Kw=FN Kw(Tavg)
1870 Mf=Fm*.02451*.3048^3/100 !Volume Flowrate of Water (m^3/s)
1880 Md=Mf*Rhow !Mass Flowrate of Water (kg/s)
1890 Vw=Mf/(PI*Di^2/4) !Water Velocity (m/s)
1900 Q=Md*Cpw*(T2-T1) !Heat Transferred to Cooling Water (W)
1910 Dtw=Q*LOG(Do/Di)/(2*PI*Kcu*L) !Temp Drop Across Tube Wall (Deg C)
1920 Twall=Twall-Dtw*.5
1930 Lmtd=(T2-T1)/LOG((Twall-T1)/(Twall-T2))
1940 P1=PI*2*Do !Heat-Transfer Perimeter At Inlet
1950 P2=PI*2*Dr !Heat-Transfer Perimeter At Exit
1960 A1=(Do-Di)*PI*Do !Heat-Transfer Area At Inlet
1970 A2=(Dr-Di)*PI*Dr !Heat-Transfer Area At Exit
1980 H1=Q/(PI*Di*L*Lmtd)
1990 M1=(H1*P1/(Kcu*A1))^.5
2000 M2=(H1*P2/(Kcu*A2))^.5
2010 Fe1=FNTanh(M1*L1)/(M1*L1) !Fin Efficiency At Inlet
2020 Fe2=FNTanh(M2*L2)/(M2*L2) !Fin Efficiency At Exit
2030 Hic=Q/(PI*Di*(L+L1*Fe1+L2*Fe2)*Lmtd)
2040 IF ABS((H1-Hic)/Hic)>.01 THEN
2050 H1=(Hic+H1)*.5
2060 GOTO 1990
2070 END IF
2080 PRINT " "
2090 PRINT USING "12X,";"Position number" : 1 2 3 4 5
2100 PRINT USING "12X,";"Wall temperature (Deg C) : ",6(DD,DD,1X);Tw(*)
2110 PRINT USING "12X,";"Average wall temperature = ",DD,DD,"" (Deg C)";Twall

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2120 PRINT USING "12X, ""Inlet water temperature = ""',DD.DD, ""' (Deg C) ""';T1
2130 PRINT USING "12X, ""Outlet water temperature = ""',DD.DD, ""' (Deg C) ""';T2
2140 PRINT USING "12X, ""Log-mean-temp difference = ""',DD.DD, ""' (Deg C) ""';Lmtd
2150! CALCULATE THE NUSSELT NUMBER
2160 Nu=Hic*Di/Kw
2170 Re=Rhow*Vw*Di/FNmu(Tavg)
2180 Cf=(FNmu(Tavg)/FNmu(Twall)).14
2190 Prw=FNPrw(Tavg)
2200 X=Re.8*Prw.3333*Cf !Compute Sieder-Tate Parameter
2210! COMPUTE COEFFICIENTS FOR THE LEAST-SQUARES-FIT
2220! STRAIGHT LINE
2230 PRINT USING "12X, ""Water velocity = ""',Z.DD, ""' (m/S) ""';Vw
2240 PRINT USING "12X, ""Sieder-Tate parameter = ""',SD.D, ""';X
2250 PRINT USING "12X, ""Nusselt number = ""',.4D.DD, ""';Nu
2260 OUTPUT @Filep:X,Nu
2270 Sx=Sx+X
2280 Sy=Sy+Nu
2290 Sxs=Sxs+X*X
2300 Sxy=Sxy+X*Nu
2310! STORE RAW DATA IN A USER-SPECIFIED FILE IF
2320! INPUT MODE (Im) = 1
2330 IF Im=1 THEN OUTPUT @File:Emf(*),T1,T2,Fm
2340 BEEP
2350 J=J+1
2360 IF Im=1 THEN
2370 INPUT "ARE YOU TAKING MORE DATA (1=YES,0=NO)?"',Go_on
2380 Nrun=J
2390 IF Go_on=1 THEN 1420
2400 ELSE
2410 IF J<Nrun THEN 1420
2420 END IF
2430 Ci=Sxy/Sxs
2440 PRINT " "
2450 PRINT USING "12X, ""Sieder-Tate Coefficient = ""',D.4D, ""';Ci
2460 Ac=0.
2470 PRINT " "
2480 PRINT USING "12X, ""Least-Squares Line: ""'
2490 PRINT USING "14X, ""Slope = ""',MD.SDE, ""';Ci
2500 PRINT USING "14X, ""Intercept = ""',MD.SDE, ""';Ac
2510 IF Im=1 THEN
2520 BEEP
2530 PRINT USING "12X, ""NOTE: ""',DD, ""' data runs were stored in file ""',.3A, ""':Nru
n.D_files
2540 END IF
2550 ASSIGN @File TO *
2560 ASSIGN @Filep TO *
2570 END
2580 DEF FNRhow(T)
2590 Ro=1006.35724-T*(.774489-T*(2.262459E-2-T*3.03304E-4))
2600 RETURN Ro
2610 FNEND
2620 DEF FNPrw(T)
2630 Pr=103*(1.09976605-T*(.013759326-T*(3.968875E-5-3.45026E-7*T)))
2640 RETURN Pr
2650 FNEND
2660 DEF FNmu(T)
2670 Mu=1.57609473E-3-T*(3.51198576E-5-T*(3.5835816E-7-T*1.365586115E-9))
2680 RETURN Mu
2690 FNEND
2700 DEF FNkw(T)

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2710 Kw=.572183504477+1.52770121209E-3*T
2720 RETURN Kw
2730 FNEND
2740 DEF FNTvsv(Emf)
2750 V=Emf*10-6
2760 T=V*(.02617334416-V*(9.2447859E-7-V*6.0746642E-11))
2770 RETURN T
2780 FNEND
2790 DEF FNCpw(T)
2800 Cpw=(4.21120858-T*(2.26826E-3-T*(4.42361E-5+T*2.71428E-7)))*1000
2810 RETURN Cpw
2820 FNEND
2830 DEF FNTanh(X)
2840 P=EXP(X)
2850 Q=EXP(-X)
2860 Tanh=(P+Q)/(P-Q)
2870 RETURN Tanh
2880 FNEND

```

```

1000! FILE NAME: PLOT
1010 PRINTER IS 705
1020 BEEP
1030 INPUT "ENTER MINIMUM AND MAXIMUM X-VALUES",Xmin,Xmax
1040 BEEP
1050 INPUT "ENTER MINIMUM AND MAXIMUM Y-VALUES",Ymin,Ymax
1060 BEEP
1070 INPUT "ENTER STEP SIZE FOR X-AXIS",Xstep
1080 BEEP
1090 INPUT "ENTER STEP SIZE FOR Y-AXIS",Ystep
1100 BEEP
1110 PRINT "IN:SP1:IP 2000,2000,8000,7000;"
1120 PRINT "SC 0,100,0,100:TL 2,0;"
1130 Sfx=100/(Xmax-Xmin)
1140 Sfy=100/(Ymax-Ymin)
1150 PRINT "PU 0,0 PD"
1160 FOR Xa=Xmin TO Xmax STEP Xstep
1170 X=(Xa-Xmin)*Sfx
1180 PRINT "PA";X,".0; XT;"
1190 NEXT Xa
1200 PRINT "PA 100,0;PU;"
1210 PRINT "PU PA 0,0 PD"
1220 FOR Ya=Ymin TO Ymax STEP Ystep
1230 Y=(Ya-Ymin)*Sfy
1240 PRINT "PA 0,";Y,"YT"
1250 NEXT Ya
1260 PRINT "PA 0,100 TL 0 2"
1270 FOR Xa=Xmin TO Xmax STEP Xstep
1280 X=(Xa-Xmin)*Sfx
1290 PRINT "PA";X,".100; XT"
1300 NEXT Xa
1310 PRINT "PA 100,100 PU PA 100,0 PD"
1320 FOR Ya=Ymin TO Ymax STEP Ystep
1330 Y=(Ya-Ymin)*Sfy
1340 PRINT "PD PA 100,";Y,"YT"
1350 NEXT Ya
1360 PRINT "PA 100,100 PU"
1370 PRINT "PA 0,-2 SR 1,5,2"
1380 FOR Xa=Xmin TO Xmax STEP Xstep
1390 X=(Xa-Xmin)*Sfx
1400 PRINT "PA";X,".0;"
1410 PRINT "CP -2,-1;LB";Xa;""
1420 NEXT Xa
1430 PRINT "PU PA 0,0"
1440 FOR Ya=Ymin TO Ymax STEP Ystep
1450 Y=(Ya-Ymin)*Sfy
1460 PRINT "PA 0,";Y,""
1470 PRINT "CP -4,-.25;LB";Ya;""
1480 NEXT Ya
1490 BEEP
1500 INPUT "ENTER X-LABEL",Xlabels
1510 BEEP
1520 INPUT "ENTER Y-LABEL",Ylabels
1530 PRINT "SR 1,5,2;PU PA 50,-10 CP";-LEN(Xlabels)/2:"0;LB":Xlabels;""
1540 PRINT "PA -11,50 CP 0,";-LEN(Ylabels)/2*5/6:"DI 0,1;LB":Ylabels;""
1550 PRINT "CP 0,0"
1560 Repeat:
1570 BEEP

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```

1580 INPUT "ENTER THE NAME OF THE DATA FILE",D_files$
1590 ASSIGN @File TO D_files$
1600 BEEP
1610 INPUT "ENTER THE BEGINNING RUN NUMBER",Md
1620 BEEP
1630 INPUT "ENTER THE NUMBER OF X-Y PAIRS STORED",Npairs
1640 BEEP
1650 INPUT "SELECT A SYMBOL FOR THE PLOTTER (1=*,2=+,3=c,4=o,5=^)",Sy
1660 PRINT "PU DI"
1670 IF Sy=1 THEN PRINT "SM*"
1680 IF Sy=2 THEN PRINT "SM+"
1690 IF Sy=3 THEN PRINT "SMc"
1700 IF Sy=4 THEN PRINT "SMo"
1710 IF Sy=5 THEN PRINT "SM^"
1720 IF Md>Npairs THEN
1730 FOR I=1 TO (Md-1)
1740 ENTER @File;Xa,Ya
1750 NEXT I
1760 END IF
1770 FOR I=1 TO Npairs
1780 ENTER @File;Xa,Ya
1790 X=(Xa-Xmin)*Sfx
1800 Y=(Ya-Ymin)*Sfy
1810 PRINT "PA",X,Y,""
1820 NEXT I
1830 BEEP
1840 ASSIGN @File TO *
1850 INPUT "DO YOU HAVE MORE DATA TO BE PLOTTED (1=YES,0=NO)?",Go_on
1860 IF Go_on=1 THEN Repeat
1870 PRINT "PU SM"
1880 BEEP
1890 INPUT "DO YOU LIKE TO DRAW A STRAIGHT LINE?",Go_on
1900 IF Go_on=1 THEN
1910 BEEP
1920 INPUT "ENTER THE SLOPE",S1
1930 BEEP
1940 INPUT "ENTER THE INTERCEPT",Ac
1950 FOR Xa=Xmin TO Xmax STEP (Xmax-Xmin)
1960 Ya=Ac+S1*Xa
1970 Y=(Ya-Ymin)*Sfy
1980 X=(Xa-Xmin)*Sfx
1990 IF Y<0 THEN
2000 Xam=(Ymin-Ac)/S1
2010 X=(Xam-Xmin)*Sfx
2020 Y=0
2030 END IF
2040 IF Y>100 THEN
2050 Xam=(Ymax-Ac)/S1
2060 X=(Xam-Xmin)*Sfx
2070 Y=100
2080 END IF
2090 PRINT "PA",X,Y,"PD"
2100 NEXT Xa
2110 END IF
2120 PRINT "PU SP0"
2130 END

```

```

10 : FILE NAME: Q_LOSS
20 : LAST UPDATED: 23 MAY 83
100  PRINTER IS 701
110  CLEAR 709
120  BEEP
130  INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)".Date$
140  OUTPUT 709;"TD":Date$
150  OUTPUT 709;"TD"
160  ENTER 709:Date$
170  PRINT USING "10X,""Month, date and time: """,14A";Date$
180  BEEP
190  INPUT "ENTER INPUT MODE (1=3054A,2=FILE)",Im
200  IF Im=1 THEN
210  BEEP
220  INPUT "GIVE A NAME FOR DATA FILE",D_file$
230  CREATE BDAT D_file$,15
240  ELSE
250  BEEP
260  INPUT "GIVE THE NAME OF THE EXISTING DATA FILE",D_file$
270  BEEP
280  INPUT "ENTER THE NUMBER OF RUNS STORED",Nrun
290  END IF
300  ASSIGN @File TO D_file$
310  BEEP
320  INPUT "GIVE A NAME FOR THE OUTPUT FILE",O_file$
330  CREATE BDAT O_file$,15
340  ASSIGN @Fileo TO O_file$
350  K=0
360  BEEP
370  INPUT "OK TO GO AHEAD (HIT ENTER)".Ok
380  IF Im=1 THEN
390  OUTPUT 709;"AR AF19 AL21"
400  OUTPUT 722;"F1 R1 T1 Z1 FL1"
410  FOR I=0 TO 2
420  OUTPUT 709;"AS SA"
430  ENTER 722:Emf(I)
440  IF I>0 THEN Emf(I)=ABS(Emf(I))*10^6
450  NEXT I
460  Tsteam=FNTvsv((Emf(1)+Emf(2))*5)
470  OUTPUT 709;"AR AF23 AL24"
480  OUTPUT 722;"F1 R1 T1 Z1 FL1"
490  FOR J=0 TO 1
500  OUTPUT 709;"AS SA"
510  ENTER 722:Emf(J+3)
520  Emf(J+3)=ABS(Emf(J+3))*10^6
530  NEXT J
540  OUTPUT @File:Emf(*)
550  ELSE
560  ENTER @File:Emf(*)
570  END IF
580  Tsteam=FNTvsv((Emf(1)+Emf(2))*5)
590  Troom=FNTvsv((Emf(3)+Emf(4))*5)
600  Power=(Emf(0)*100)^2/5.76*1.E-3
610  Dt=Tsteam-Troom
620  PRINT USING "10X,3D.3D,3(DDD.DD,2X)";Power,Tsteam,Troom,Dt
630  K=K+1
640  IF Im=1 THEN
650  BEEP

```

```
660 INPUT "ARE YOU TAKING MORE DATA (1=YES,0=NO)?" Go_on
670 IF Go_on=1 THEN 380
680 ELSE
690 IF K<Nrun THEN 380
700 END IF
710 END
720 DEF FNTvsv(V)
730 T=V*(.02617334416-V*(9.2447859E-7-V*6.0746642E-11))
740 RETURN T
750 FNEEND
```

Month, date and time: 06:01:14:55:20

The following analysis was performed for data in file DD10

Position number	:	1	2	3	4	5	6
Wall temperature (Deg C)	:	66.92	65.43	62.00	57.65	65.81	58.03
Average wall temperature	=	61.55	(Deg C)				
Inlet water temperature	=	23.94	(Deg C)				
Outlet water temperature	=	26.32	(Deg C)				
Log-mean-temp difference	=	36.42	(Deg C)				
Water velocity	=	1.37	(m/S)				
Sieder-Tate parameter	=	5342.8					
Nusselt number	=	158.72					

Position number	:	1	2	3	4	5	6
Wall temperature (Deg C)	:	68.20	66.10	61.57	55.55	65.90	58.93
Average wall temperature	=	61.42	(Deg C)				
Inlet water temperature	=	25.36	(Deg C)				
Outlet water temperature	=	27.39	(Deg C)				
Log-mean-temp difference	=	35.03	(Deg C)				
Water velocity	=	1.92	(m/S)				
Sieder-Tate parameter	=	7032.7					
Nusselt number	=	199.76					

Position number	:	1	2	3	4	5	6
Wall temperature (Deg C)	:	68.10	65.85	60.61	54.03	65.49	57.68
Average wall temperature	=	60.48	(Deg C)				
Inlet water temperature	=	26.77	(Deg C)				
Outlet water temperature	=	28.59	(Deg C)				
Log-mean-temp difference	=	32.79	(Deg C)				
Water velocity	=	2.47	(m/S)				
Sieder-Tate parameter	=	8634.8					
Nusselt number	=	247.76					

Position number	:	1	2	3	4	5	6
Wall temperature (Deg C)	:	67.70	65.11	59.70	52.58	64.40	56.49
Average wall temperature	=	59.34	(Deg C)				
Inlet water temperature	=	28.28	(Deg C)				
Outlet water temperature	=	29.94	(Deg C)				
Log-mean-temp difference	=	30.22	(Deg C)				
Water velocity	=	3.01	(m/S)				
Sieder-Tate parameter	=	10181.6					
Nusselt number	=	302.10					

Position number	:	1	2	3	4	5	6
Wall temperature (Deg C)	:	66.69	64.08	58.48	51.22	63.06	55.10
Average wall temperature	=	58.04	(Deg C)				
Inlet water temperature	=	29.73	(Deg C)				
Outlet water temperature	=	31.19	(Deg C)				
Log-mean-temp difference	=	27.58	(Deg C)				
Water velocity	=	3.56	(m/S)				
Sieder-Tate parameter	=	11676.1					
Nusselt number	=	347.19					

Position number	:	1	2	3	4	5	6
Wall temperature (Deg C)	:	67.18	64.46	58.95	51.63	63.76	55.68
Average wall temperature	=	58.53	(Deg C)				
Inlet water temperature	=	31.91	(Deg C)				
Outlet water temperature	=	33.28	(Deg C)				



Log-mean-temp difference = 25.93 (Deg C)  
 Water velocity = 3.84 (m/S)  
 Sieder-Tate parameter = 12518.8  
 Nusselt number = 371.81

Position number : 1 2 3 4 5 6  
 Wall temperature (Deg C) : 70.32 67.36 62.08 55.23 66.98 59.06  
 Average wall temperature = 61.84 (Deg C)  
 Inlet water temperature = 33.57 (Deg C)  
 Outlet water temperature = 35.09 (Deg C)  
 Log-mean-temp difference = 27.51 (Deg C)  
 Water velocity = 3.29 (m/S)  
 Sieder-Tate parameter = 11223.3  
 Nusselt number = 331.04

Position number : 1 2 3 4 5 6  
 Wall temperature (Deg C) : 74.00 71.28 65.83 58.91 70.63 62.82  
 Average wall temperature = 65.70 (Deg C)  
 Inlet water temperature = 35.46 (Deg C)  
 Outlet water temperature = 37.16 (Deg C)  
 Log-mean-temp difference = 29.38 (Deg C)  
 Water velocity = 2.74 (m/S)  
 Sieder-Tate parameter = 9850.0  
 Nusselt number = 284.11

Position number : 1 2 3 4 5 6  
 Wall temperature (Deg C) : 77.43 74.65 69.49 62.86 74.08 66.46  
 Average wall temperature = 69.42 (Deg C)  
 Inlet water temperature = 37.27 (Deg C)  
 Outlet water temperature = 39.19 (Deg C)  
 Log-mean-temp difference = 31.18 (Deg C)  
 Water velocity = 2.19 (m/S)  
 Sieder-Tate parameter = 8354.8  
 Nusselt number = 240.23

Position number : 1 2 3 4 5 6  
 Wall temperature (Deg C) : 80.70 77.96 73.09 67.18 77.57 70.37  
 Average wall temperature = 73.22 (Deg C)  
 Inlet water temperature = 38.92 (Deg C)  
 Outlet water temperature = 41.23 (Deg C)  
 Log-mean-temp difference = 33.12 (Deg C)  
 Water velocity = 1.64 (m/S)  
 Sieder-Tate parameter = 6722.9  
 Nusselt number = 200.30

Sieder-Tate Coefficient = .0294

Least-Squares Line:  
 Slope = 2.93533E-02  
 Intercept = 0.00000E+00

Month, date and time :05:30:15:27:15

The following analysis was performed for data in file DR1

Measured pressure = 9.579E+04 (Pa)  
Pressure corresponding to measured steam temp = 9.010E+04 (Pa)  
Noncondensable gas concentration = 5.8 (Vol %)  
Noncondensable gas concentration = 9.0 (Mass %)

Water velocity = 0.82 (m/S)  
Reynolds number = 13139.2  
Inside heat-tran coef = 5356.2 (W/m<sup>2</sup>-K)  
Overall-heat-trans coef = 3393.6 (W/m<sup>2</sup>-K)  
Heat flux = 2.22899E+05 (W/m<sup>2</sup>)  
Outside heat-tran coef = 19990.5 (W/m<sup>2</sup>-K)  
Nusselt coefficient = 11304.5 (W/m<sup>2</sup>-K)  
Nus coef (from heat flux) = 10797.9 (W/m<sup>2</sup>-K)

Water velocity = 1.64 (m/S)  
Reynolds number = 26418.9  
Inside heat-tran coef = 9074.3 (W/m<sup>2</sup>-K)  
Overall-heat-trans coef = 4109.5 (W/m<sup>2</sup>-K)  
Heat flux = 2.68764E+05 (W/m<sup>2</sup>)  
Outside heat-tran coef = 11186.9 (W/m<sup>2</sup>-K)  
Nusselt coefficient = 10320.1 (W/m<sup>2</sup>-K)  
Nus coef (from heat flux) = 10005.0 (W/m<sup>2</sup>-K)

Water velocity = 2.47 (m/S)  
Reynolds number = 40022.4  
Inside heat-tran coef = 12466.1 (W/m<sup>2</sup>-K)  
Overall-heat-trans coef = 4725.9 (W/m<sup>2</sup>-K)  
Heat flux = 3.06851E+05 (W/m<sup>2</sup>)  
Outside heat-tran coef = 10550.9 (W/m<sup>2</sup>-K)  
Nusselt coefficient = 9822.2 (W/m<sup>2</sup>-K)  
Nus coef (from heat flux) = 9484.8 (W/m<sup>2</sup>-K)

Water velocity = 3.29 (m/S)  
Reynolds number = 53980.1  
Inside heat-tran coef = 15667.3 (W/m<sup>2</sup>-K)  
Overall-heat-trans coef = 5331.5 (W/m<sup>2</sup>-K)  
Heat flux = 3.43200E+05 (W/m<sup>2</sup>)  
Outside heat-tran coef = 10926.6 (W/m<sup>2</sup>-K)  
Nusselt coefficient = 9511.1 (W/m<sup>2</sup>-K)  
Nus coef (from heat flux) = 9075.4 (W/m<sup>2</sup>-K)

Water velocity = 3.84 (m/S)  
Reynolds number = 63586.5  
Inside heat-tran coef = 17728.9 (W/m<sup>2</sup>-K)  
Overall-heat-trans coef = 5652.2 (W/m<sup>2</sup>-K)  
Heat flux = 3.61307E+05 (W/m<sup>2</sup>)  
Outside heat-tran coef = 11060.4 (W/m<sup>2</sup>-K)  
Nusselt coefficient = 9359.5 (W/m<sup>2</sup>-K)  
Nus coef (from heat flux) = 8889.1 (W/m<sup>2</sup>-K)

NOTE: 5 X-Y pairs were stored in plot data file PDR1

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**DAT**  
**FILM**

```
2070 END IF
2080 PRINT " "
2090 PRINT USING "12X,""Position number      : 1 2 3 4 5
6""
2100 PRINT USING "12X,""Wall temperature (Deg C) : ""6(DD.DD,1X)";Tw(*)
2110 PRINT USING "12X,""Average wall temperature = ""6(DD.DD,1X) (Deg C)"";Twall
```

2640 RETURN  
2650 FNEHD  
2660 DEF FNMu(T)  
2670 Mu=1.57609473E-3-T\*(3.51198576E-5-T\*(3.5835816E-7-T\*1.365586115E-9))  
2680 RETURN Mu  
2690 FNEHD  
2700 DEF FNkw(T)





1530 PRINT "SR 1.5,2:PU PA 50,-10 CP":-LEN(Xlabels)/2:"U:LB":Xlabels:  
1540 PRINT "PA -11,50 CP 0,":-LEN(Ylabels)/2\*5/6:"DI 0.1;LB":Ylabels:""  
1550 PRINT "CP 0,0"  
1560 Repeat:!  
1570 BEEP

2100 NEXT Xa  
2110 END IF  
2120 PRINT "PU SP0"  
2130 END

```
600 Power: (Len(T0)-100)/2/3/10 VLE 0  
610 Dt=Tsteam-Troom  
620 PRINT USING "10X.3D.3D.3(DDD.DD.2X)";Power,Tsteam,Troom,Dt  
630 K=K+1  
640 IF Im=1 THEN  
650 BEEP
```



Position number : 1 2 3 4 5 6  
Wall temperature (Deg C) : 67.18 64.46 58.95 51.63 63.76 55.68  
Average wall temperature = 58.53 (Deg C)  
Inlet water temperature = 31.91 (Deg C)  
Outlet water temperature = 33.28 (Deg C)

